Fundamentals of ELECTRICITY

McDOUGAL ★ DUNLAP ★ RANSON

Fundamentals of

ELECTRICITY

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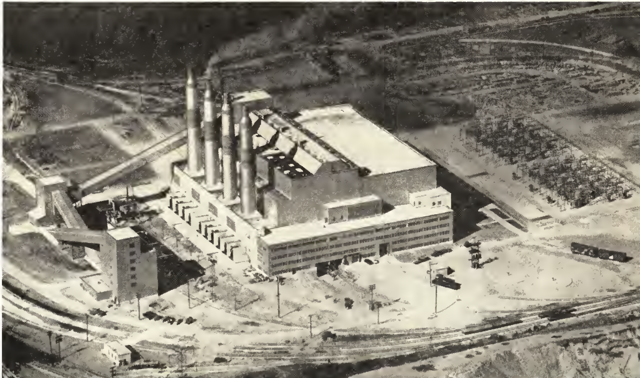

HUGE PLANTS ARE NEEDED TO GENERATE POWER FOR LARGE INDUSTRIAL AREAS

This generating plant is located near Chicago, Illinois, and it will be capable of developing 600,000 kilowatts. The transformers and switch gear are shown in the yard at the right of the station.

Fundamentals of

ELECTRICITY

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[ILLUSTRATED]

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PREFACE

The authors of this book have illustrated and explained electrical principles by observing and describing objects and occurrences with which the student is familiar; then examples are given of their practical application and everyday uses. Thus each principle is clearly understood and remembered.

Many symbols and diagrams are used on electrical blueprints, and pages of illustrated symbols are presented to aid the reader in learning and remembering these symbols. Beside each symbol is shown a picture of the object it represents; in many cases a cut-away view is used; in others the object is shown pulled apart in order to illustrate its construction.

Several pages of standard electrical abbreviations and formulas are given, as well as standard diagrams for the following: single, three- and four-way switches; range circuits; direct-current generators; direct-current, single-phase, and three-phase motors; controllers. Also included is a chart of the current-carrying capacity of copper wire used for interior electric wiring work; the latest National Electrical Code Standards for different types of insulation and under various wiring conditions are also given.

Electrical terms that may cause difficulty are simply and clearly explained in the Dictionary of Electrical Terms included in the book.

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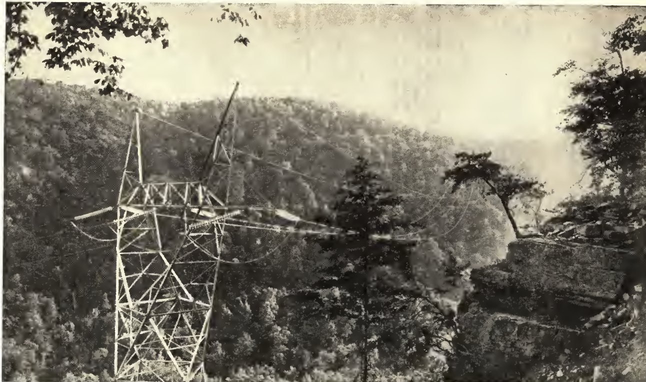


TRANSMISSION LINES CARRY ELECTRIC POWER AT HIGH VOLTAGE FROM THE GENERATING STATION TO CONSUMER LOCATIONS, WHICH MAY BE MANY MILES AWAY

Courtesy of Aluminum Company of America, Pittsburgh, Pa.

ELECTRICITY AND MAGNETISM

MAGNETISM

NATURAL AND ARTIFICIAL MAGNETS

Magnetite. It has been known for many centuries that some specimens of the ore known as magnetite have the property of attracting small bits of iron and steel. This ore probably received its name from the fact that it is abundant in the Province of Magnesia in Thessaly, although the Latin writer Pliny says that the word magnet is derived from the name of the Greek shepherd, Magnes, who, on the top of Mount Ida, observed the attraction of a large stone for his iron crook. Pieces of ore which exhibit this attractive property for iron or steel are known as *natural magnets*.

Magnet as Compass. It was also known to the ancients that artificial magnets might be made by stroking pieces of steel with natural magnets. Not until the twelfth century, however, was the discovery made that a suspended magnet would assume a north and south position. Because of this property, natural magnets came to be known as *lodestones* (leading stones), and magnets, either artificial or natural, began to be used for determining directions. The first mention of the use of a compass in Europe was in 1190. The instrument is thought to have been introduced from China.

Magnets which retain their magnetism for a long time are called *permanent* magnets. The permanency of an artificial magnet is greatly increased by placing a piece of soft iron, called an *armature*, or *keeper*, across the free ends.

Making Artificial Magnets. *Method of Single Touch.* There are several ways in which artificial magnets may be produced. The method of single touch consists in stroking a piece of steel from end to end with one pole of an artificial or a natural magnet.

Method of Divided Touch. The method of divided touch is that of stroking a piece of steel from its center to one end with one pole of an artificial or a natural magnet and then from its center to the other end with the remaining pole of the magnet.

Fig. 1. Bar Magnet

Method of Double Touch. The procedure in the case of double touch consists in applying both poles of a horseshoe magnet to a piece of steel and then moving the magnet several times along the steel first in one direction and then in the other.

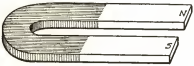


Fig. 2. Horseshoe Magnet

Artificial magnets may also be produced by passing electric currents about pieces of iron or steel in a manner to be described later.

The form shown in Fig. 1 is called a *bar* magnet; that shown in Fig. 2, a *horseshoe* magnet.

Poles of a Magnet. If a magnet is dipped into iron filings, the filings are observed to cling in tufts near the ends, but scarcely at all near the middle, Fig. 3. These places near the ends of the magnet, in which its strength seems to be concentrated, are called the *poles* of the magnet. It has been decided to call the end of a freely suspended magnet which points to the north the *north-seeking* or *north pole*, and it is commonly designated by the letter N. The other end is called the *south-seeking* or *south pole*, and is designated by the letter S. The direction in which the compass needle points is called the *magnetic meridian*.


Fig. 3. Location of Poles of Magnet

Laws of Magnetism. *Dissimilarity of Poles.* In the experiment with the iron filings, no particular difference was observed between the action of the two poles. That there is a difference, however, may be shown by experimenting with

two magnets, either of which may be suspended, Fig. 4. If two N poles are brought near each other, they are found to repel each other. The S poles likewise are found to repel each other. But the N pole of one magnet is found to be attracted by the S pole of another. The results of these experiments may be summarized in a general law: *Magnet poles of like kind repel each other, while poles of unlike kind attract.*

Force of Attraction or Repulsion. The force of attraction is found, like gravitation, to vary inversely as the square of the distance between the poles, that is, separating two poles to twice their original distance reduces the force acting between them to one-fourth its original value, while separating them to three times their original distance reduces the force to one-ninth its original value, etc.

Unit Strength of a Magnetic Pole. A unit magnetic pole is one of such a strength that when placed at a distance of one centimeter ($\frac{13}{33}$ inch) *from a similar pole of equal strength it repels it with a force of one dyne* ($\frac{1}{27800}$ ounce).

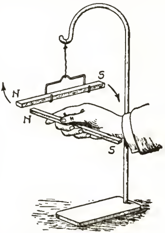


Fig. 4. Experiment Proving Law of Magnetic Attraction and Repulsion

Magnetic Substances. The only common magnetic substances are iron and steel. Nickel has a little attraction when you bring a very strong or powerful magnet near it. There are a few substances such as bismuth and antimony which are actually repelled instead of being attracted, but the effect is small. These substances are scarce and expensive and are not used often.

Nearly all of the other metals may be classed as non-magnetic substances because they do not behave or act like iron and steel when they are brought near to a magnet. The most important of these non-magnetic metals are copper, aluminum and brass.

Many other substances, such as air, wood, paper, and also liquids are classified as non-magnetic substances or materials, because they are not acted upon or attracted by magnets. Many of these substances however are used when it is necessary to have some non-magnetic material that is not a metal.

MAGNETIC INDUCTION

Magnetizing by Induction. If a small unmagnetized nail be suspended from one end of a bar magnet, it will be found that a second nail may be suspended from this first one, which itself acts like a magnet, a third suspended from the second, and so on, as shown in Fig. 5. If now the bar magnet be carefully pulled away from the first nail, the others will instantly fall away from each other, showing that the nails were strong magnets only so long as they were in contact with the bar magnet.

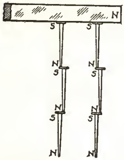


Fig. 5. Experiment Showing Magnetic Induction

Any piece of soft iron may be thus magnetized *temporarily* by holding it in contact with a permanent magnet. Indeed, it is not necessary that there be actual contact. If a nail simply be brought near to the permanent magnet it will be found to have become a magnet. This fact may be proved experimentally by holding one end of a nail near to a permanent magnet and then presenting some iron filings to the other end, as shown in Fig. 6. If the permanent magnet be removed, most of the iron filings will immediately fall from the end of the nail, thus showing that its magnetization was purely temporary and due to the presence of the permanent magnet. *Magnetism produced in this way by the mere presence of adjacent magnets, without contact, is called induced magnetism.* If the induced magnetism of the nail in Fig. 6 be tested with a compass needle, it will be found that the *remote* induced pole S' is of the same kind as the inducing pole S, while the *near pole* N is of unlike kind. This is the general law of magnetic induction.

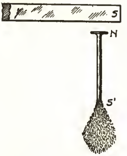


Fig. 6. Example of Magnetic Induction

Magnetic induction explains the fact that a magnet attracts an unmagnetized piece of iron. It first magnetizes the piece of iron by induction, thereby producing two poles near the ends, the end near the pole of the magnet being of unlike character to that pole, and therefore being attracted, and the one at the other end of the piece of iron being of like character to the inducing pole of the

magnet and therefore repelled. Since the latter pole is farther away from the magnet, its repulsion is overbalanced by the attraction existing between the pole on the magnet and the adjacent unlike pole that it induces in the iron. The result, therefore, is that the iron is drawn toward the magnet. Magnetic induction also explains the formation of the tufts of iron filings shown in Fig. 3, Each little filing becomes a temporary magnet, the end of each filing which points toward the inducing pole of the magnet being unlike this pole, and the end which points away from it being like the inducing magnet pole. The bush-like appearance is due to the repulsive action which the outside free poles of the filings exert upon each other.

Permeability and Retentivity. Under the influence of a magnetic pole of given strength some substances become more magnetic than others. For example, with the same inducing pole, soft iron will show more magnetism than will steel. The degree of magnetization resulting in a substance from a given strength of inducing pole is called its *permeability*.

A piece of soft iron will become a strong magnet very easily, but when removed from the influence of the inducing magnet, it will lose practically all of its magnetism. On the other hand, a piece of steel is not so easily magnetized as the soft iron, but it will retain a much larger fraction of its magnetism after it has been removed from the influence of the permanent magnet. The power of resistance to magnetization and demagnetization is called *retentivity*. Thus steel has a much greater retentivity than wrought iron, and, in general, the harder the steel the greater the retentivity.

Permeability is measured by the amount of magnetization which a substance is able to receive under the action of an inducing pole of a given strength, while retentivity is measured by the tenacity with which it holds or retains magnetization when the action of the inducing pole is removed.

REPRESENTATION OF MAGNETIC FIELDS

Magnetic Lines of Force. If we could separate the N from the S pole of a small magnet so as to obtain an independent N pole and were then to place this N pole near the N pole of a bar magnet, our free N pole would move over to the S pole of the bar magnet along some curved path similar to that shown in Fig. 7. The reason

that the motion is along a curved rather than along a straight path is that the free N pole is at one and the same time repelled by the N pole of the bar magnet and attracted by its S pole, and the relative strengths of these two forces are continually changing as the relative distances of the moving pole from these two poles are changed.

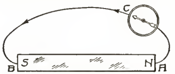


Fig. 7. Method of Plotting Lines of Force in Magnetic Field

It is not difficult to test this conclusion experimentally. Thus if a bar or horseshoe magnet is placed just beneath a flat dish containing water, Fig. 8, and a cork carrying a magnetized needle placed near the N pole in the manner shown in the figure, the cork will be found to move in a curved path from N around to S. In this case the cork and the needle actually move as would an independent pole, since the upper pole of the needle is so much farther from the magnet than the lower pole that the influence of the former on the motion is very small.

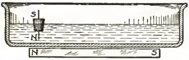


Fig. 8. Experimental Proof of Magnetic Action Along Lines of Force

Any path which an independent N pole would take in going from N to S is called a *line of magnetic force*. The simplest way of finding the direction of this path at any point near a magnet is to hold a compass needle at the point considered, for the needle must obviously set itself along the line in which its poles would move if independent, that is, along the line of force which passes through the given point C, Fig. 7.

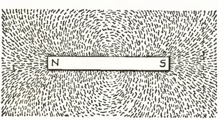


Fig. 9. Magnetic Field of Bar Magnet

Magnetic Fields of Force. The region about a magnet in which its magnetic forces can be detected is called its *field of force*. The simplest way of gaining an idea of the way in which the lines of force are arranged in the magnetic field about any magnet is to sift iron filings upon a piece of paper placed immediately over the magnet. Each little filing becomes a temporary magnet by induction and, therefore, like the compass needle, sets itself in the direction of the line of force.

Fig. 9 shows the shape of the magnetic field about a bar magnet. Fig. 10 is the ideal diagram corresponding to Fig. 9 and showing the lines of force emerging from the N pole and passing around in curved lines to the S pole. This way of imagining the lines of force to be closed curves passing on the outside of the magnet from N around to S and on the inside of the magnet from S back to N was introduced by Faraday about 1830, and has been found of great assistance in correlating the facts of magnetism. Fig. 11 shows the directions of lines of force about a horseshoe magnet.

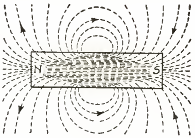


Fig. 10. Ideal Magnetic Field of Bar Magnet

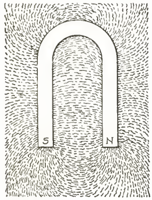


Fig. 11. Magnetic Field of Horseshoe Magnet

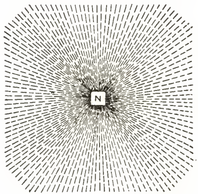


Fig. 12. Arrangement of Lines of Force about End of Bar Magnet

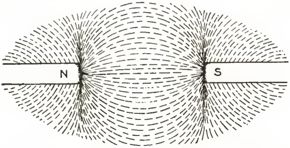


Fig. 13. Arrangement of Lines of Force about the Two Dissimilar Poles of Two Bar Magnets

Fig. 12 illustrates the magnetic field about the north pole of the bar magnet. The magnetic lines are simply radial.

The field produced when unlike poles N and S of two bar magnets are brought close together is shown in Fig. 13.

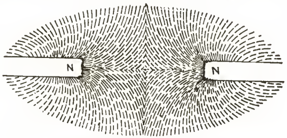


Fig. 14. Arrangement of Lines of Force about the Two Similar Poles of Two Bar Magnets

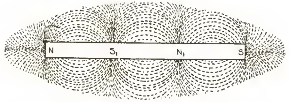


Fig. 15. Salient Poles (N and S) and Consequent Poles (N_1 and S_1)

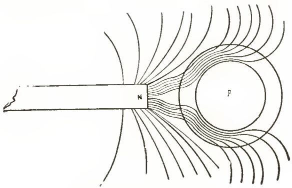


Fig. 16. Effect of Magnetic Screen

The magnetic field resulting from bringing near each other the like poles N and N or S and S of two bar magnets is illustrated in Fig. 14.

Consequent Poles. A piece of steel may be irregularly magnetized by touching it with a strong magnet at several points

along its length. A magnet thus produced is called an *anomalous* magnet. The poles which are, in this case, located at the ends of the magnet are called *salient* poles, and the intermediate ones are called *consequent* poles. A piece of steel magnetized in this way virtually consists of several bar magnets put end to end, but in a reversed order with like poles adjacent to each other. The field of an anomalous magnet is shown in Fig. 15.

Attraction through Bodies. If a piece of glass, wood, paper, or any other nonmagnetic substance be placed between a magnet and a piece of iron or other magnetic substance, it will be found that attraction occurs between the magnet and the magnetic substance as if nothing were interposed.

If, however, a small magnet or a piece of iron or steel be placed inside of a hollow ball made of iron, no outside magnet will affect it. The reason for this phenomenon is that the lines of magnetic force are conducted around the pieces of iron enclosing them. The condition outlined above is clearly shown in Fig. 16.

NATURE OF MAGNETISM

Proofs of Molecular Nature of Magnetism. *Effect of Heat.* If a magnetized needle is heated red hot, it will lose its magnetism

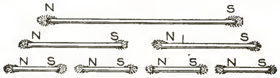


Fig. 17. Magnetic Nature of Fragments of Bar Magnet

completely. Again, if any magnet is jarred or hammered or twisted, the strength of its poles as measured by their ability to pick up tacks or iron filings will be greatly diminished.

These facts point to the conclusion that magnetism has something to do with the arrangement of the molecules, since causes which violently disturb the molecules of the magnet weaken its magnetism.

Breaking a Magnet. Again, if a magnetized needle be broken, each part will be found to be a complete magnet. That is, two new poles will appear at the point of breaking—a new N pole on the part which has the original S pole, and a new S pole on the part which has the original N pole. The subdivision may be continued indefi-

nitely, but always with the same result, as indicated in Fig. 17. This fact points to the conclusion that the molecules of a magnetized bar are themselves little magnets arranged in rows with their opposite poles in contact, Fig. 19.

Effect of Jarring a Magnet. If an unmagnetized piece of hard steel be pounded vigorously while it lies between the poles of a magnet, or if it be heated to redness and then allowed to cool in this position, it will be found to have become magnetized. This fact indicates that in an unmagnetized bar of iron or steel, it is probable that the molecules themselves are tiny magnets which are arranged either at random or in little closed groups or chains, as in Fig. 18; so that, on the whole, opposite poles neutralize each other throughout the bar. But when the bar is brought near a magnet, the molecules are swung around by the outside magnetic force so as to arrange themselves in rows, in some such manner as that shown by Fig. 19. According to this view, the reason that heating and jarring weaken a magnet is that disturbances of this sort tend to shake the molecules out of alignment. On the other hand, heating or jarring facilitate magnetization when an unmagnetized bar is between the poles of a magnet because they assist the magnetizing force in breaking up the molecular groups or chains and getting the molecules into alignment.

Fig. 18. Molecular Nature of Magnetism. Condition of Molecules in Unmagnetized Bar

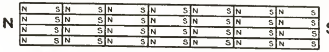


Fig. 19. Theoretical Arrangement of Molecules in Saturated Bar Magnet

An interesting working model illustrating this theory may be made by filling a test tube with iron filings. If the tube be stroked from one end to the other with a magnet, it will be found to behave toward a compass needle as if it were itself a bar magnet, but it will lose its magnetism as soon as the filings are shaken up. The iron filings represent the molecules in a magnet. When subjected to the action of a magnet, the little iron particles become magnetized with their similar poles pointing one way; the tube as a whole then behaves as a magnet. But when the iron filings are shaken up, so that their

individual poles no longer point in one direction and therefore neutralize each other, the tube ceases to be a magnet.

Soft iron has higher permeability than hard steel, merely because the molecules of the former substance do not offer so much resistance to a force tending to swing them into line as do those of the latter substance. Steel has, on the other hand, a much greater retentivity than soft iron, because its molecules are not so easily moved out of position when once they have been aligned.

Saturated Magnets. Strong evidence for the correctness of the above view is found in the fact that a piece of iron or steel cannot be magnetized beyond a certain limit, no matter how strong the magnetizing force. This limit probably corresponds to the condition in which the axes of all the molecules are brought into

Fig. 20. Laminated Bar Magnet

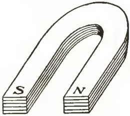


Fig. 21. Laminated Horseshoe Magnet

parallelism, as in Fig. 19. The magnet is then said to be *saturated,* since it is as strong as it is possible to make it.

Compound Magnets. It has been found that long thin magnets in the form of either sheets or wires are more powerful in proportion to their weight than are magnets constructed of solid material. A magnet of great strength can be made by riveting together saturated sheet magnets. The most powerful permanent magnets are made by placing a number of similarly magnetized, saturated steel wire magnets side by side with their poles adjacent. Figs. 20 and 21 are examples of compound magnets of the bar and horseshoe types.

Earth's Magnetism. The fact that a compass needle always points north and south, or approximately so, indicates that the earth itself is a great magnet having an S magnetic pole near the geographical north pole and an N magnetic pole near the geographical south pole; for the magnetic pole of the earth which is near the

geographical north pole must, of course, be unlike the pole of a suspended magnet which points toward it, and the pole of the suspended magnet which points toward the north is the one which, by convention, it has been decided to call the north pole. In the past this pole of the compass was sometimes referred to or termed the "north seeking pole."

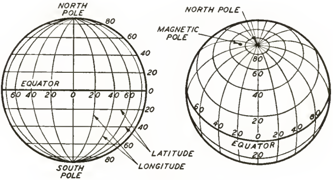


Fig. 22. Location of Magnetic Pole

The magnetic pole of the earth which is near the north geographical pole was found in 1831 by Sir James Ross in Boothia Felix, Canada, latitude 70° 30′ N., longitude 95° W. It was located again in 1905 by Captain Amundsen at a point a little farther west. Its approximate location is 70° 5′ N. and 96° 46′ W. See Fig. 22. It is probable that it slowly shifts its position.

It is, of course, on account of the fact that the earth's magnetic and geographical poles do not altogether coincide that the magnetic needle does not point exactly north, and also that the direction in which it does point changes as the needle is moved about over the earth's surface. This last fact was first discovered by Columbus on his voyage to America and caused great alarm among his sailors. There are other local causes, however, such as large deposits of iron ore, which cause local deviations of the needle from the true north. The number of degrees by which the needle varies from the north and south line at a given point is called the *declination* at that particular location.

Inclination, or Dip. Let an unmagnetized knitting needle

a, Fig. 23, be thrust through a cork, and let a second needle b be passed through the cork at right angles to a. Let the system be adjusted by means of wax or a pin c until it is in neutral equilibrium about b as an axis when a is pointing east and west. Then let a be strongly magnetized by stroking one end of it from the middle out with the N pole of a strong magnet and the other end from the middle out with the S pole of the same magnet. When now the needle is replaced on its supports and turned into a north-and-south line, with its N pole toward the north, it will be found, in the north temperate zone, to dip so as to make an angle of from 60° to 75° with the horizontal. This shows that in the latitudes mentioned the earth's magnetic lines are not at all parallel to the earth's surface. The angle between these lines and the earth's surface is called the *dip*, or *inclination*, of the needle. At Washington it is 71° 5′; at Chicago, 72° 50′; at the magnetic poles it is, of course, 90°; and at the so-called magnetic equator—an irregular curved line passing through the tropics—the dip is 0°.

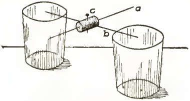


Fig 23. Simple Experiment Illustrating Dip

Earth a Great Magnet. A very instructive way of showing that the earth acts like a great magnet is to hold any ordinary iron or steel rod parallel to the earth's magnetic lines (that is, about in the geographical meridian, but with the north end slanting down at an angle of, say 70°) and then strike one end a few blows with a hammer. The rod will be found to have become a magnet, with its upper end an S pole, like the north pole of the earth, and its lower end an N pole. If the rod be reversed and tapped again with the hammer, its magnetism will be reversed. If held in an east-and-west position and tapped, it will become demagnetized, as is shown by the fact that both ends of it will attract either end of a compass needle.

The above experiment should be performed carefully and a delicate compass used in testing the rod.

The shape of the magnetic field and the displacement of the magnetic and geographical poles are shown in Fig. 24. It will be seen that the direction of most of the lines of force is from the N magnetic pole out through space and that the lines of force re-enter

near the south magnetic pole. There are a few lines of force that leave the earth's surface below the equator and re-enter above the equator. A careful study of the diagram will assist us in seeing that the earth's magnetic field resembles that of a bar magnet, as shown in Fig. 10.

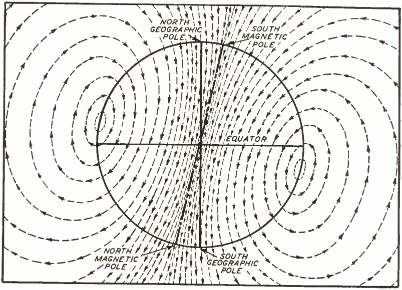


Fig. 24. Direction of Magnetic Field about the Earth

Flow of Magnetic Lines. The action of a magnet and magnetic field may be easier understood if they are compared with a water system and thought of as flowing through space. In Fig. 25 the pump forces the water up and through the pipe to the water motor where the water is discharged into the pool. As soon as the pool fills up, the water runs down the hill back to the pond, ready for another trip around the route or circuit.

If a bar magnet is placed inside an ordinary soft iron horseshoe, Fig. 26, the magnetism will flow through the horseshoe similar to the circuit or route taken by the water. This route or circuit in Fig. 26 is called the magnetic circuit. It is customary to indicate the direction of the magnetic lines of force by arrows on the dotted lines. The direction of flow is from the North seeking pole through air or iron to the South seeking pole of the bar magnet, and then through

the magnet to the North pole. In Fig. 26 it will be seen, by comparing the circuit with Fig. 10, that more of the lines of force go through the iron and less loop around through the air from one pole to another. This is because soft iron is a better conductor of magnetism or

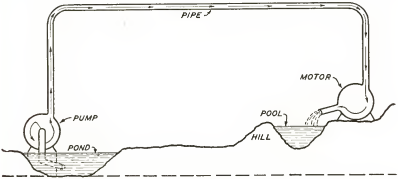


Fig. 25. Flow of Water through a Pipe System

magnetic lines of force than air. It is well to remember that the magnetic lines of force leave the magnet at the North pole and return to it at the South pole. However, always be sure to think of these lines as a complete circuit, or route. This method is a convenient one for representing the direction and amount of force in space.

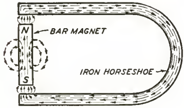


Fig. 26. Flow of Magnetic Lines of Force through a Horseshoe

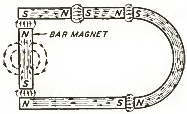


Fig. 27. Flow of Magnetic Lines of Force through Iron Bars

A small compass can be used to locate the direction at any point of the magnetic lines of force. The marked or North seeking end of the compass will point in the direction toward which the magnetic lines of force are flowing.

Several soft iron bars can be arranged to form a magnetic path or circuit, as shown in Fig. 27. In this case each of the iron bars

becomes a temporary bar magnet, with magnetic poles as marked. The iron bars will tend to pull together and to the poles of the bar magnet, closing up the air gaps. As soon as the bar magnet is removed, however, the other iron bars will lose their magnetism and magnetic polarity.

Magnetic Poles in Generator and Motor. The horse shoe permanent magnets were inverted and used to provide magnetism

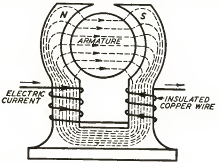


Fig. 28. Flow of Magnetic Lines of Force through an Early Bipolar Dynamo

for the armature in the early electric generators. The inner ends of the pole pieces were curved to correspond to the armature in order to produce uniform magnetic flux distribution. The direction of the magnetic lines of force and circuit are shown by the dotted lines in Fig. 28. It will be seen that in the gap between the armature and pole pieces the lines of force pass radially between the poles and armature.

It was discovered later that stronger magnetic fields could be produced by passing electric current through a coil of insulated copper wire than could be produced by permanent magnets. Thus a coil of wire was wound around each pole of the frame, Fig. 28, and an electric current passed through the coil causing the iron core to become a magnet and to produce magnetic lines of force that flow through the same circuit as the permanent magnet. In this way an electromagnet is produced. It has replaced the permanent magnet in all generators and motors and all other apparatus where a supply of electric current is available. In generators and motors these coils of insulated wire are called field coils, because they produce a magnetic field.

The shape or path of the magnetic field for a motor or generator has changed from that of the early type, Fig. 28, to that shown in Fig. 29 for the two-pole generators and Fig. 30 for the four-pole generators. The change in shape of the frames of electric motors and generators was made to provide a short and more efficient magnetic path. In Fig. 29, the magnetic lines of force produced by the field coils divide at the left and half of the magnetic lines of force go

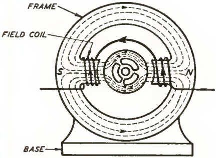


Fig. 29. Magnetic Path in a Modern Two-Pole Generator or Motor

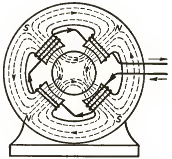


Fig. 30. Magnetic Path in a Four-Pole Generator or Motor

through the upper part of the frame, the other half through the lower part of the frame to the right-hand coil which is the North pole of the machine. The direction of flow of the magnetic lines of force in generators and motors is from the North pole across the gap to the armature, through it to the gap to the South pole into the frame, through which it returns to the starting point at the North pole. In the four-pole generators and motors there are four magnetic paths, two for each pair of poles. The direction of the lines of force are shown in Fig. 30. The magnetic paths in larger generators and motors having six, eight or more poles are similar to those in the four-pole generators.

REVIEW QUESTIONS

1. What is *inclination* as applied to the earth's magnetism and what does it indicate?

2. What happens when the north pole of a bar magnet is brought close to the north pole of another magnet? Why?

3. How are the earth's magnetic and geographic poles located with respect to one another?

4. A small compass is placed inside of a hollow soft-steel sphere. If a bar magnet is brought near this sphere, will the compass needle change position? If so, why? If not, why?

5. A long bar magnet is broken into three parts. Will the center section become a magnet? If so, why? If not, why not?

6. What is *declination* as applied to the earth's magnetic field?

7. What is a permanent magnet?

8. Make a sketch of the magnetic field surrounding a bar magnet and indicate the direction of the lines of force.

9. What direction do the magnetic lines of force take through the earth? Through space?

10. Describe a simple method of making an artificial magnet.

APPLICATIONS TO INDUSTRY

1. How are magnetic fields produced today in electrical generators?

2. How many magnetic paths do you find in the early bipolar generator? In the modern two-pole generator? In the modern four-pole generator?

3. Name three nonmagnetic metals. Name three nonmetallic, nonmagnetic materials.

4. Describe the path and direction of the magnetic lines of force when a straight bar magnet is placed across the ends of a soft-iron horseshoe.

5. Which provides an easier path for magnetic lines of force—air or soft iron? Why?

6. When referring to magnetism, what do you mean by *permeability? Retentivity?*

7. A mariner's compass is usually enclosed in a brass case. Why is brass used?

8. Many automobile ignition coils have magnetic cores composed of a bundle of wires rather than of solid iron. Why is this so?

9. Most transformers are enclosed in cases made of *steel,* rather than brass, copper, or aluminum. From your knowledge of magnetism, explain why this is so.

10. Look around your home, school, office, or shop. Name at least four devices that utilize the principles of magnetism.

THE ELECTRON THEORY

Classifications. Material things can be classified under the general categories of *matter* and *energy*. Matter can be defined as anything which occupies space and has weight. This will be true of any tangible substance, and such a substance can be measured in terms of either the weight or dimensions. On the other hand, energy is intangible; it can be observed or represented merely by its effects on matter and can be defined as the capacity for doing work. Energy can take on various forms, such as mechanical energy, chemical energy, heat energy, and electrical energy. Any of these forms can be transferred from one form to the other. In a limited system there has never been observed a loss or gain in the total energy. This is known as the law of conservation of energy. Another way to state this law is to say that energy can neither be created nor destroyed.

In the study of electricity it is many times convenient to approach it from an energy viewpoint, and the law of conservation of energy should always be borne in mind. Electrical energy can be divided into three general classifications—static electricity, dynamic or current electricity, and magnetism. Each can be converted into the others. As was stated before, energy is measured by its effects on matter. These effects are usually such as to produce motion. From this viewpoint, the unit for energy is equal to the force necessary to produce the motion multiplied by the distance the object is moved—hence, the expression *foot-pounds*. The unit of electrical energy, although it could be expressed in foot-pounds, is expressed in *joules*. The joule will be used to arrive at other fundamental electrical units.

Electrons. For our purpose in the study of electricity, it is important to understand the subdivisions into which matter can be divided. Consider water as an example. Water is matter, for certainly it occupies space and has weight. Depending on the temperature, it may exist as a liquid, a solid, or a gas, under the common names of water, ice, or steam. Regardless of the tempera-

ture, it will still have the same composition. Starting with a bucket of water, if half is poured out and half is retained, and this process continued, eventually a quantity of water will be obtained which cannot be further divided without it ceasing to be water. This amount is a molecule of water. If this molecule of water is divided, instead of having two parts of water, there will be one part of oxygen and two parts of hydrogen (H_2O). Hydrogen and oxygen are both gases at normal temperature and pressure. If a quantity of hydrogen is repeatedly subdivided, a molecule of hydrogen will finally be obtained. Likewise if a quantity of oxygen is repeatedly subdivided, a molecule of oxygen will finally be obtained. In this case, unlike water, the molecule can be further subdivided and the substance still remains hydrogen or oxygen as the case may be.

When a molecule of hydrogen or oxygen is subdivided, there will be two atoms of hydrogen or two atoms of oxygen. From the above considerations, it is concluded that the molecule is a natural particle of matter which is composed of two or more atoms. There is an exception to this statement, for in a few substances the molecule and the atom are identical. The oxygen molecule has two atoms of oxygen; the hydrogen molecule has two atoms of hydrogen; and the water molecule has two atoms of hydrogen along with one atom of oxygen.

Matter which is composed of only one kind of atom is an *element*. There are 96 different elements. Oxygen, hydrogen, iron, carbon, and copper are a few examples of elements. Matter which is composed of more than one kind of atom is called a *compound*. Most of the substances in the world are compounds. Water, wool, cloth, salt, and sugar are a few examples of compounds. For a long time it was thought that the atom was the smallest subdivision of matter. In recent years, a theory has been advanced which explains much of the observed electrical phenomena. According to this theory, the atom is not the smallest subdivision of matter. Each of the 96 different kinds of atoms are composed of *electrons* and *protons*. In other words, all matter is composed of just two things, electrons and protons; furthermore, the electrons and protons from one element are identical to those from any of the other elements. The reason that there are 96 different kinds

of elements is not that they are composed of different constituents, but that the arrangement of the electrons and protons is different for the different elements. The electron is the smallest negative charge of electricity which is known of at the present time. The proton is a small, natural, positive charge of electricity. Although this is still considered to be theory, scientists have measured the

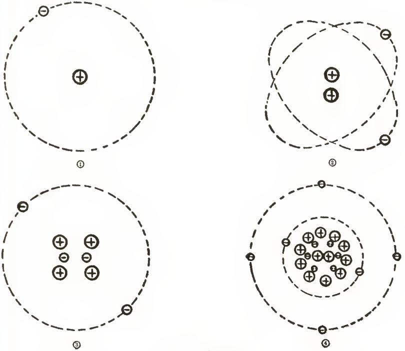


Fig. 1. Atomic Structure

mass and size of the electron and proton. Also, they know how much charge each possesses. The electron and proton each have the same charge, although the mass of the proton is many times that of the electron. Some scientists think that the proton is composed of a *positron* and a *neutron*, the positron having the same mass and charge as the electron and the neutron having no electrical charge. The electrons and protons of the atoms are arranged in similar manner to our solar system. The protons form a positive nucleus around which the electrons rotate. In our solar system the Sun would represent the nucleus, and the Earth, Mars, Venus,

and the other planets would represent the electrons. The hydrogen atom has the simplest structure. It has one proton for the nucleus and one electron rotating about it. Other atoms are more complicated with many protons in the nucleus and a like number of electrons rotating at various distances from the center and in various directions.

Fig. 1 shows several of these atom structures. Fig. 1 ① shows the simplest atom; ② and ③ are atoms with a slightly more complex structure; and ④ is supposed to represent a carbon atom. Note that in Fig. 1 ③ and ④ there are a few electrons trapped inside the nucleus. These might be called *nuclear electrons.*

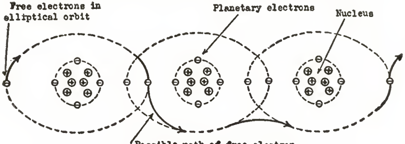


Fig. 2. Possible Travel Route of Free Electrons

The different atomic structures cause the 92 elements to possess different properties. Some are hard while others are soft; some are brittle and others are elastic; some will burn and some will not. These properties and other physical and chemical properties, as well as the electrical properties of matter, are determined by the structure of their atoms—the way atoms go together to make molecules and the arrangement of the molecules.

There are many important electrical properties but only two will be considered here. They have the same relation to each other as the physical properties, hardness and softness. These two electrical properties are called *conductance* and *resistance.* Conductance is the ability of a substance to conduct electricity, that is, allow electricity to flow through it. Resistance is the measure of the ability of a substance to oppose the flow of electricity through it. As would be expected, it is not the positive nucleus or protons that flow, as they are down inside the atom and also are much heavier (have more mass) than the electrons. In addition, many of the

electrons are rotating so close to the nucleus that they never leave the atom. These electrons are called *planetary electrons*. Other electrons are rotating at relatively greater distances from the nucleus, probably in elliptical orbits such that the orbits from one atom overlap the orbits of the next atom. These electrons are not attached tightly to any one atom and are termed *free electrons*. Fig. 2 shows how these free electrons may travel from atom to atom. Note that the method does not attempt to simulate any particular material or show how any actual free electron does travel, but merely shows how it is possible for the free electrons to travel from atom to atom as chance or some force may dictate. The relative number of free electrons has a definite bearing on the conductance or resistance of the material. The substance with the greater number of free electrons will be the better conductor and will have the higher conductance. A substance with only a few free electrons has a high resistance. Substances with practically no free electrons are called *insulators* or *nonconductors*.

Static Electricity. Static electricity was originally considered to be electricity at rest. Now, since the electrons and protons have been considered as the ultimate charges of electricity, and it has been seen that in the atoms the electrons are in continual motion, it might be better to consider static electricity as being electricity associated with insulators or dielectrics. Lightning discharges and the crackling sounds in a radio receiver on a hot summer night are manifestations of static electricity.

Bodies can be charged with static electricity by various methods. A charged body merely means that the object has more or less than its normal number of electrons. In the uncharged state, each atom has an equal number of electrons and protons, so in order to charge a body, since the electrons are rotating outside the nucleus, it is merely necessary to remove some of these electrons in order to charge the body positively. In this case there will be an excess of protons, or positive charges, since some of the negative electrons have been removed. Now the question arises, "Where did these electrons which were removed go to?" The logical answer is that they must now be on some other object, causing it to be negatively charged. In other words, any object with more than its normal number of electrons is considered to be

charged negatively. It has been proved experimentally that charged bodies act upon each other with a force of attraction when unlike charges are concerned, and a force of repulsion when like charges are concerned. From this observation it is concluded that electrons and protons attract each other; also, that electrons repel other electrons, and protons repel other protons. This force of attraction or repulsion changes with the magnitude of the charges and also with the distances between them. A law can be stated that charged bodies attract or repel each other with a force that is directly proportional to the product of the charges, and inversely proportional to the square of the distance between them. This law can be expressed as follows:

$$F = \frac{qq'}{d^2}$$

The unit of electrical charge could be taken as that charge associated with an electron or proton. This would not be practical due to its small magnitude. The practical unit of charge is called the *coulomb*, and is approximately equal to the charge on 6,280,000,000,000,000,000 electrons. It is easier to express such a large number by saying it is equal to 6.28×10^{18}. To understand this method of representing large numbers, the student should verify the fact that 500 is equal to 5×10^2, and that 520 is equal to 5.2×10^2, and that 5,200 is equal to 5.2×10^3. By actually verifying these relatively small numbers it will be easier to see how to represent very large numbers by this system.

Electrostatic or Dielectric Field of Force. The region surrounding and between charged bodies is called the *dielectric field of force.* Electrostatic field and electric field are other names given to this region of force. It is just as logical to call this region or space which is full of force a field of force, as it is to call a region or space which is full of corn or wheat a field of corn or a field of wheat. Since this force will act through free space or even through a vacuum, it can be seen that it is different from ordinary force and needs special consideration. Force can be applied by striking a sharp blow or exerting a steady pressure. It can also be delivered through connecting links, such as a chain or tow rope, or can be evenly distributed over wide areas, such as the pressure of the water

on a dam or the pressure of the air inside an automobile tire. These methods and others are more or less familiar to the average person, and all of them are applied directly or through some mechanical connecting link. A field of force differs from these in that it requires no physical or mechanical connecting link but can be applied through free space or even through a vacuum.

Fields of force permeate the space surrounding certain objects and, in general, diminish in proportion to the square of the distance from the source of origin. A field of force can be defined as a region or space where force is present. The force of gravity is a field of force that permeates the space surrounding the earth, and acts through free space causing all unsupported objects to fall to the earth. Newton developed the law of gravitation, which states that every object attracts every other object with a force that is directly proportional to the product of the masses and inversely proportional to the square of the distance between them. Notice the similarity between this law and the law of attraction of charged bodies. It is the gravitational field that holds the universe together. With no gravitational field the planets, including the earth, would, instead of revolving around the sun, fly off at a tangent, and travel through space on their own hooks. The moon would cease to revolve about the earth, and due to the earth's rotation, objects on its surface would be thrown out into space like mud from a bicycle wheel. The atoms are similar to our solar system in that electrons are revolving at a tremendous velocity around the positive protons of the atom. Since these revolving electrons do not fly off at a tangent, there must be a field of force between them and the protons. The reason that it must be a field of force is that there are no connecting links between the revolving electrons and the protons of the nucleus. Relatively speaking, there are great distances between the electrons and the protons, even in apparently solid matter. It has been estimated that if a copper one-cent piece were enlarged to the size of the earth's orbit around the sun (approximately 186,000,000 miles), the electrons would be the size of baseballs, and they would be, on the average, 3 miles apart. The field of force between the electrons and protons in the atom is the same as the dielectric field associated with charged bodies. In practice when the dielectric or

electrostatic field is spoken of, this interatomic field is not meant, but reference is made only to the external field about charged bodies.

Lines of Force. In order to visualize the various properties of fields of force and their relation to electrical phenomena, it is convenient to represent them by *lines of force*. These lines of force are imaginary lines used to represent the intensity and direction of the field under consideration. It is impossible to imagine enough lines to represent all the paths through space along which the force acts, and on paper only a very few can be drawn, and those only in one plane. But even so, if a few lines are drawn to give a general idea of the field's shape, direction, and relative intensity, something has been accomplished. The direction is indicated by an arrowhead and the field strength or intensity is indicated by the density or number of lines per unit area. The direction of a force can be taken as the direction a small test object moves or tends to move when acted on by the force. To get the direction of the current of a river, it would be better to test it with a cork or chip than just to make the general statement that the current is downhill, for at a bend eddy currents might be set up which would actually be flowing uphill. The cork or chip as a test object would check this. A test object for wind must be something light like a flag or column of smoke, but a test object for determining the direction of the earth's gravitational field must be a dense heavy object. By using a small heavy object like a brick, the earth's gravitational field can be tested for direction and will be found always to act toward the center of the earth. To test the direction of a dielectric field, the test object could either be a small positive charge or a small negative charge, because the force of a dielectric field will act on either. It has arbitrarily been agreed by all concerned to use a small positive charge when determining the direction of a dielectric field. In other words, the field about an isolated positive charge is away from the charge, and a positive test charge would be repelled. The field about an isolated negative charge is toward the charge, and a positive test charge would be attracted. The field between a positive and negative charge is from positive to negative for the same reason.

Fig. 3 shows the dielectric field about isolated charges represented by lines of force.

Figs. 4 and 5 show the resultant fields about like and unlike charges.

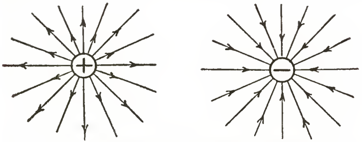


Fig. 3. Left, Dielectric Field About a Positive Charge (Electron); Right, Dielectric Field About a Negative Charge

Note in Figs. 4 and 5 how the lines of force apparently repel each other. In Fig. 4, although the two charges are attracted, the lines of force between the two are not parallel but bulge out at the center as if they were repelling each other. Also note that where they do this they are in the same direction, that is,

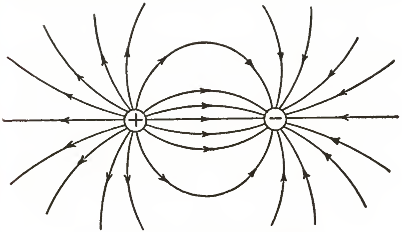


Fig. 4. Dielectric Field About Two Unlike Charges

from left to right on the paper. In Fig. 5, the lines of force which are in the region between the charges apparently are repelling each other as is evidenced by their being bent. Also these particular lines of force are in the same direction. Instead

of saying like charges repel, the law can be stated: Dielectric lines of force in the same direction repel each other. In dealing with certain electrical phenomena this rule is very convenient and useful.

Characteristics of Dielectric Fields. If a rubber rod or comb is briskly rubbed with a piece of fur or woolen cloth, a number of

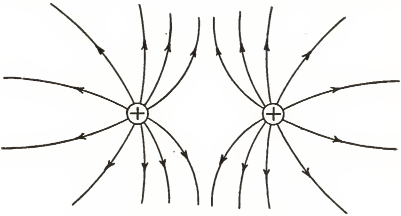


Fig. 5. Dielectric Field About Two Like Charges

electrons from the fur or cloth adhere to the rubber. If the two are separated immediately, the rubber has an excess of electrons, or is negatively charged. If two pith balls are oppositely charged by touching one of them with the rubber and the other with the cloth or fur, they will have an attraction for each other showing that a force is present. (See Fig. 6.) Hence a dielectric field has

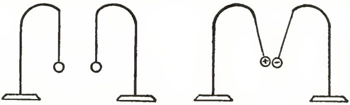


Fig. 6. Left, Pith Balls Uncharged; Right, Attraction Between Opposite Charges

been established. It was necessary to do work against the force of attraction in separating the charged bodies, but this energy would be regained if the bodies were allowed to come together as a result of the force of attractions between them. Hence, energy may be stored in a dielectric field.

If the negatively charged rubber rod be moved a great distance away from the cloth or fur, a dielectric field still exists in the space around it. This may be demonstrated by picking up bits of paper with the rod or by charging both of the pith balls from it. The pith balls now show a force of repulsion between them. This is still a dielectric field. (See Fig. 7.)

If an external force is used to bring the two charged pith balls

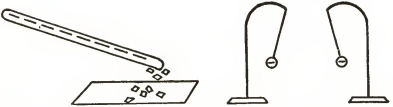


Fig. 7. Left, Force of Attraction of Charge Rod; Right, Repulsion Between Similar Charges

closer, work is done and the force of repulsion is increased, or the field is increased. The energy consumed in increasing the field is recovered when the external force is removed. It will be used up in returning the pith balls to their original positions. Here again it is shown that: *energy is necessary to establish or increase a field, force is necessary to maintain it, and recoverable energy is stored in the field.*

If one negatively charged pith ball is isolated and the negatively charged rubber rod is brought up toward it from any direc-

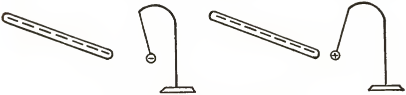


Fig. 8. Effect of Field About a Charged Body

tion, a force of repulsion will be shown to be present. If the pith ball had been positively charged, a force of attraction would have been noted, no matter from which direction the negatively charged rod approached. (See Fig. 8.) The conclusion, then, is that *a dielectric field entirely surrounds a charged body.*

Many other striking and interesting experiments in connection with dielectric fields may be performed by using a static machine and the associated equipment which are usually found in physics laboratories. (See Fig. 9.) One of these experiments which verifies

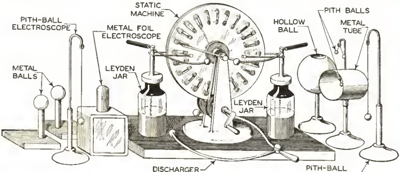


Fig. 9. Static Generator and Associated Equipment

the fact that there is no dielectric field inside a charged hollow sphere shows why shielded radio components are not affected by dielectric fields.

Potential. Potential is "short" for potential energy and represents energy due to position. The water at the top of Niagara Falls possesses an enormous amount of potential energy due to its position. This potential energy is converted into kinetic energy as it falls. The amount of potential energy a certain quantity of water has at the top of Niagara Falls is equal to the work necessary to move that amount of water from the center of the earth to the top of the falls. This potential energy is really stored in the earth's gravitational field. Similarly, a point located in a dielectric field can be considered to possess an electrical potential or potential energy due to its position in the dielectric field, and can be measured by the work required to move a unit charge from infinity up to that point. If work must be performed in moving a positive charge up to that point, the point in question is at a positive potential. If work must be performed to move a negative charge to the point, it is at a negative potential. From the above consideration it can be seen that the units for potential are work or energy units per unit charge. In the case of electrical potential, *volt* was adopted as the unit and equals one joule per coulomb.

Potential Difference. In practice, it is not the absolute potential that we are interested in but the difference of potential. In the case of Niagara Falls it is not the work that would result if the water at the top were to return to the center of the earth—this would represent the absolute potential of the water at the top; the problem is the work that results when the water moves from the top to the bottom of the Falls. Numerically, this is equal to the difference between the potential at the top of the Falls and that at the bottom. Likewise, in electricity it is the difference in potential between two points that is of importance.

This difference of potential is measured in volts and is equal to the work or energy necessary to move a unit charge from one point to the other point. If a unit charge is free to move, the difference of potential is equal to the energy expended by the field in moving the unit charge from one point to the other. In practice the only charges that are free to move are the free electrons in a conductor. If the ends of a conductor are connected to points which are not at the same potential, the free electrons will move or flow toward the higher potential. That is, if one end of the conductor is connected to a point of negative potential and the other end to a point of positive potential, the free electrons will flow from negative to positive until both points are at the same potential. On the other hand, if both points are at a positive potential, then the free electrons will flow from the lower positive potential to the higher positive potential until both points are at the same potential. Likewise, if both points are at a negative potential, the free electrons will flow from the point at the greater negative potential to the point at the lesser negative potential until both points are at the same potential. In other words, the free electrons will flow as long as there is a potential difference and a conducting path. This flow of free electrons in a conductor is called an *electric current.*

If no work is required to move a unit charge from infinity to a certain point, then according to the definition of potential that point is at zero potential. To find a point at zero potential, it would be necessary to go an infinite distance from all charges to get out of their dielectric field. It can be seen from the above that absolute zero potential has no practical meaning, but

since there can be a positive and a negative potential there should be some place to refer to as zero potential.

In the case of mechanical potential energy, the water at the top of Niagara Falls would have to flow down to the center of the earth to be at zero potential. This is also impractical, so it was arbitrarily agreed that the largest portion of the earth which was at the same level, and hence the same potential, would be called zero level. This is sea level, for the oceans cover the majority of the earth's surface and are so large that millions of gallons of water can be removed or added without appreciably lowering or raising this level.

Similarly, if a large enough conductor could be connected, an immense quantity of electricity could either be removed or added without appreciably raising or lowering its potential. The earth's crust is just such a conductor. For this reason the earth has arbitrarily been chosen to represent zero potential. To put some object at the potential of the earth (zero potential), a good connection must be made to the soil moisture by connecting to a large water pipe system or to a large amount of buried conducting material. This is referred to as *ground* by the practical electrician. Most all electrical installations are grounded at some place.

Another example of a relative zero value is zero temperature. When zero is reached it does not mean that it can get no colder. It only means that the temperature has reached a value which a group of men arbitrarily agreed to call zero. In one system it is the temperature of melting ice.

Electromotive Force (e.m.f.). Electromotive force and electrical pressure are other terms used to express a difference in electrical potential. Electromotive force is the force that causes electricity to move through a conductor. As it is electrons that move, e.m.f. might better be called electron moving force which is nothing more than a dielectric field of force such as exists between points at different potential. Hence, a potential difference (p.d.) and an e.m.f. represent the same thing.

In the early days, electricity was considered to act like a mythical fluid that flowed through the wires similar to water flowing through a pipe. From this viewpoint, a pressure was required, hence the term *electrical pressure*. This term is still used and

represents the same condition as p.d. or e.m.f. Now potential, force, and pressure are not usually measured in the same units. It may seem strange that the volt, a unit of work per charge, can be used as a unit of force and a unit of pressure. Academically speaking, the volt is not the proper unit for force or pressure, but to the practical man, since p.d., e.m.f., and electrical pressure all represent the same set of conditions, the same unit will suffice.

Similarly, the pound is a unit of force and not a unit of pressure, but it is common to speak of so many pounds pressure in automobile tires. Also, the foot and the millimeter are both units of length or distance and not pressure, but such expressions as "a pressure of 30 feet," meaning the pressure resulting from water dammed up 30 feet high, or a "pressure of 730 millimeters," meaning the pressure required to support a column of mercury 730 mm. high, are frequently heard. The symbol usually used to represent a voltage, p.d., e.m.f., or electrical pressure is E. V is also used as a symbol for the volt.

Electric Current. An electric current is said to flow when the free electrons drift or move along a conductor. Electric current is a direct result of an e.m.f. and will continue as long as the e.m.f. exists between the ends of the conductor. The rate at which the electrons pass a given section of the conductor is a measure of the current's magnitude, and is *one* when one unit of quantity passes in one unit of time, that is, a coulomb per second.

This unit of current is called the *ampere* and can also be defined as the current that is flowing when 6.28 times 10^{18} electrons are passing a point each second. As was stated before, the charge from 6.28 times 10^{18} electrons represents the quantity of electrical charge in a practical coulomb. The symbol that is usually used to represent electric current is I. A is also used as a symbol for the ampere.

Direction of Current Flow. The free electrons which constitute an electric current flow from a point of low potential to a point of higher potential; that is, the free electrons are pulled or attracted toward the higher potential. In general, this would be from negative to positive, although as was explained before, it could be from positive to a greater positive or from a negative to a lesser negative value. In the early days of electricity, before

anything was known of the electron theory, and electric current was considered to be the flow of some mythical fluid, naturally it was thought that the current would flow from a higher to a lower potential similar to the way water flows in a pipe connecting two reservoirs which are at different levels. Certain rules were developed on this assumption, and even after the electron theory was developed authors were hesitant in changing the rules. Only in recent years have certain authors of radio texts developed new rules or changed the old ones as to the actual flow of current. The rules that need to be changed are very few and the changes very simple. The reason for changing the rules is that difficulty is encountered in presenting the vacuum tube theory from any other viewpoint than the electron flow. On the other hand, in connection with ordinary electrical phenomena the direction makes no difference. Exactly the same result will be obtained by either the old or the new conception of current flow. Nevertheless, it is important for the student to understand the essence of the above discussion in order that no confusion will result from the use of either method of presenting the direction of current flow.

Resistance. When an electric current flows through a conductor, the motion is relatively a slow drift, probably only a few inches per second. The slowness of the electron movement is due to the fact that the free electrons which constitute the current are constantly colliding with other electrons, protons, atoms, molecules, or the nucleus of atoms, consequently retarding their progressive motion toward a point of higher potential. On the other hand, it must not be thought that the actual velocity of individual electrons is low. If it were not for the constant collisions mentioned above, the electrons would actually reach velocities many, many times as great, and the magnitude of the current would be limited only by the time the e.m.f. was applied. This condition need not be considered, as collisions take place in all conductors. Not only do these collisions retard the motion but set a limit to the magnitude of current (number of amperes) that will flow under a certain set of conditions. This opposition to the flow of current is called *resistance,* and as was mentioned before is one of the important electrical properties of matter.

The unit of resistance is the *ohm.* The value of the ohm may

be defined in several ways. Since the volt and the ampere have already been defined it is a simple matter to define the ohm in terms of them. The ohm is that amount of resistance which will limit the current to 1 ampere when 1 volt is applied. In other words, 1 volt of e.m.f. can force 1 ampere of current through 1 ohm of resistance. R is the symbol usually used to represent resistance; Ω is used as a symbol for ohm. This is discussed fully in the section on Ohm's Law.

Laws of Resistance. The laws of resistance were first investigated by Ohm, who showed that the resistance of a given conductor varies directly as its length and inversely as the area of its cross section. He also showed that it depends upon the material of which the conductor is composed. This can be stated as follows: $R = \frac{KL}{S}$ where L is the length, S the area of the cross section, and K is a constant depending for its value on the material, the units used for L and S, and the temperature. In other words, for a given material and at a fixed temperature, doubling the length causes the resistance to be twice as much or doubling the cross-sectional area causes the resistance to be just one-half what it was before.

The resistance of all substances changes as their temperature varies. The resistance of all metals increases as their temperatures rise; on the other hand, the resistance of most liquid and nonmetallic conductors decreases with an increase of temperature. The amount of change in resistance per ohm per degree is called the *temperature coefficient.*

Ability to prepare standards of resistance which should be independent of temperature is highly desirable. Certain alloys have practically a zero temperature coefficient, and are suitable for use in measuring instruments and where it is important that the value of resistance remain constant as the temperature changes.

Conductance. As was stated previously, conductance is an electrical property of matter and is the reciprocal of resistance. The unit of conductance is the *mho*, and the symbol is G. The relation of conductance and resistance can be expressed as follows:

$$G = \frac{1}{R} \text{ or } R = \frac{1}{G}$$

REVIEW QUESTIONS

1. What is *matter? Energy?*

2. What is an *atom?* An *electron?* A *proton?* A *nucleus?* An *element?* A *compound?*

3. Name some of the common elements of which matter is composed.

4. If all matter is composed of electrons and protons, why are there so many (96) different kinds of atoms, or elemental substances?

5. In what way do the arrangement and movement of electrons and protons resemble our solar system?

6. When we say that a body is charged with static electricity, what do we mean according to the electronic theory?

7. If two bodies in close proximity bear a static charge with respect to one another, what is the region existing between them called?

8. Draw a simple sketch to show the field existing in space about two *unlike* charges. About two *like* charges.

9. What is the difference between *potential energy* and *kinetic energy?*

10. In electricity, what is the unit of potential difference? Define it. Compare potential difference with electromotive force.

11. According to the electron theory, what is a *current flow?* What direction does it take? What is the unit of current flow?

12. With respect to current flow, what is *resistance?* What is the unit of resistance?

13. What is a *mho,* and what relation does it bear to the *ohm?*

APPLICATIONS TO INDUSTRY

1. Copper is a better conductor of electrical current than iron. How is this explained according to the electron theory?

2. In many plants using large leather or rubber belts to transmit power, why is it necessary to ground all metal parts of the machinery?

3. What causes a large electrical discharge, in the form of lightning, to occur between two clouds, or between a cloud and the ground?

4. What is the purpose of a *lightning rod?*

5. What characteristic of the atomic or molecular structure of a substance makes it a good nonconductor or insulator?

6. Which has the greater resistance, a wire 10 feet long or a wire 20 feet long, both of the same diameter?

7. Which has the greater resistance, a wire $\frac{1}{10}$-inch in diameter or a wire $\frac{1}{2}$-inch in diameter, both of the same length?

8. What is the purpose of a *ground?*

9. If one conductor has a resistance of 1 ohm, and another has a resistance of 10 ohms, which will permit the greater flow of current? How much more?

10. What is the difference between the old concept of current flow and the new electronic concept of current flow?

ELEMENTARY CIRCUITS

FLOW OF ELECTRIC CURRENT

Electricity is put to work through the use of circuits. Just as in other fields of work where a variety of things are accomplished by changing the methods used, so it is in electricity that a variety of work is accomplished by the different forms of circuits.

The action of electricity, or the flow of electric current, is in many respects very similar to water, but in some cases the action is just the opposite to that of water. Water will flow out of the end of an open hose, Fig. 1, when that end of the hose is lower than the surface of the water in the barrel. Electricity or electric current will

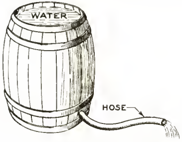


Fig. 1. Water Flowing Out of a Hose

not flow out of the end of an open wire because the air with which it comes in contact is an insulator, just as rubber is, and acts to prevent current from flowing out of the bare wire just as a cork put in the end of a hose would stop the water from flowing out of the hose onto the ground.

Since electricity will not flow out of the ends of the wire, a circuit must be formed in order to have a flow of electric current through the wires.

But what is a circuit? If you should go north from your home several miles to the next town, then east to the next town, then south to another town, and from there return to your home, you would refer to this as the route you had taken. If you made this trip every day, or once every week, you would probably refer to these

towns as being on your route or circuit. This route or circuit is somewhat similar to a circle, in that you go from one point around to another, then to another, and finally arrive at your starting point.

An electrical circuit is the path or route that an electric current takes in flowing from one place through a wire, conductor, or apparatus, on to the next, and to the next, etc., finally arriving at the starting place. If you take the two wires connected to a lamp and bend them around in a circle, Fig. 2, and splice the two ends together, you have a complete circuit. Starting at the splice you can trace the curved wire *A* to the bottom of the lamp, through the lamp and the curved wire *B* to the splice, which is where you started. There will,

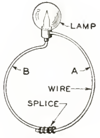


Fig. 2. Lamp and Loop of Wire

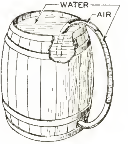


Fig. 3. End of Hose Put in Top of Barrel

however, not be any flow of electric current through this circuit, Fig. 2, because there is nothing connected in this circuit that will produce an electrical pressure which would cause an electric current to flow. A condition similar to Fig. 2 is shown in Fig. 3 when the end of the hose is put into the top of the barrel. There will be water in both ends of the hose, but there will not be any water flowing up through the hose. In order to have a flow of water through the hose, it is necessary to have pressure.

Now suppose that the rubber hose, Fig. 3, is cut in two, the piece at the bottom of the barrel is connected to the bottom of the pump, Fig. 4, and the piece at the top is fastened to the top of the pump. Then work the handle of the pump slowly up and down. This will force water up through the pump and hose into the top of the barrel. The flow of water through the hose, pump, and barrel is shown by

arrows, Fig. 4. This flow of water is produced by applying pressure downward on the pump handle.

A similar action will occur in an electrical circuit when the ends of the wires A and B, Fig. 2, are connected to the terminals or binding posts of the dry cell, as shown in Fig. 5. The dry cell produces pressure in the electrical circuit just as the pump does in Fig. 4. In Fig. 5 the electricity or electric current will flow from the positive (+) terminal or binding post of the dry cell through the wires to the lamp, through the filaments of the lamp to produce the light, then through the wire to the negative (−) terminal of the dry cell. This flow of current is represented by short arrows in Fig. 5.

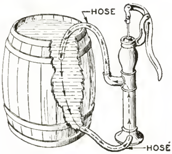


Fig. 4. Illustration of Pump Forcing Water to Circulate through Pump, Hose, and Barrel

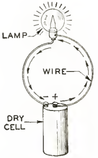


Fig. 5. Illustrating Flow of Current in Circuit

It will be noted that the current flows in one constant direction in the performance of this work. It does not reverse itself, but continues in this direction. You can, however, reverse this current in the circuit by changing the connections of wires to the battery, so that the current will enter the circuit from the opposite side and start to flow in the opposite direction. If certain classes of devices such as lamps, door bells, and motors make up this load, the work will go on as before and no difference will be seen. If, however, certain polarized devices such as meters are in the circuit, you may have to reverse these connections before the meters will show a reading. This will lead you to believe, and rightly, that care must be used when assembling the devices and apparatus which go to make up a circuit.

Many such devices are polarized, that is, must have their poles or terminals connected to certain sides of the circuit, and so must be connected to a circuit in a manner as was intended by their maker. Polarized devices and instruments are usually marked with plus and minus signs upon their binding posts or else stamped with positive and negative or their abbreviation pos. or neg. Fig. 6 gives you an illustration showing a direct-current voltmeter which must be connected into a circuit in a certain manner. This meter has one of

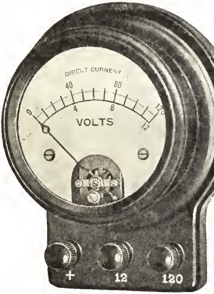


Fig. 6. A Direct-Current Meter Which Must Be Placed in a Circuit with the Terminal Marked "Plus" Attached to the Positive Wire of the Circuit. It is a "Polarized" device.
Courtesy of Jewel Electric Company

its binding posts marked with a plus, which indicates that this terminal must be connected to the positive side of this circuit. This is the manner in which it will be connected in order that the meter will show a reading on its scale. If the connection to the circuit was made in the wrong terminal or current was supplied to the meter in the wrong direction, then the indicating needle of this would tend to deflect in the opposite direction—a direction which is off the scale,

and since it is kept from going far in that direction by the stop pin, the needle would probably be bent and ruined.

Unless so marked, devices are rarely polarized, and non-polarized devices will operate successfully if placed in the circuit with the current running in either direction.

TRACING ELECTRICAL CIRCUITS

One of the most important things for an electrician and engineer to know is how to trace the flow of an electric current through a circuit. When it rains, the water always runs down hill, or from a higher place to a lower one. Electric current always flows from a place having higher (voltage) pressure through the circuit to a place having lower pressure. This is similar to a water system in that the water flows from a high overhead tank through a pipe to the faucets in the different homes.

The positive terminal of a dry cell, of a wet cell, of a storage battery, or of an electric generator is nearly always considered as the terminal having the higher pressure. An electric current is usually considered as flowing from the positive through the external circuit to the negative terminal. The positive terminal of a dry cell, storage battery, or electric generator is usually marked with the letters **POS, P**, or the plus (+) sign. The positive terminal of storage batteries and the positive leads of some electric machines are often marked with paint. Some of the manufacturers of storage batteries paint the positive terminal of the battery with red paint. The plus (+) sign is used to show the positive terminal on drawings and wiring diagrams. When a battery is represented on a drawing or diagram by the symbol |ǀ|ǀ, the long thin line is considered the positive terminal. In electric wiring work when black and white wires are used, the black wire is usually considered the positive wire when tracing the flow of current through the circuit. The negative terminal is usually marked **NEG, N**, or with a minus (−) sign.

A SIMPLE ELECTRICAL CIRCUIT

The flow of an electric current through an electric circuit may be compared with the motion of a tight string with a knot fastened around two wheels, Fig. 7. One of the wheels has a handle fastened to it. When this wheel is turned by the handle,

the string will move and turn wheel *2*. There are several arms extending outward from wheel *2*, and when this wheel turns, these arms will strike one end of the hammer and push that end down. This causes the other end of the hammer to strike the gong and ring it. The faster the handle on wheel *1* is turned, the faster the

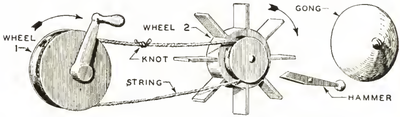


Fig. 7 A Method of Transmitting Power from One Place to Another

string and wheel *2* will move, and the faster the hammer will strike the gong. The string between wheels *1* and *2* is used to transmit the power from wheel *1*, which is turned by the handle, to wheel *2*, which rings the gong.

In an electrical circuit, Fig. 8, the copper wires take the place of the string in Fig. 7. The dry cell takes the place of wheel *1*—the power for turning the wheel. The bell coils take the place

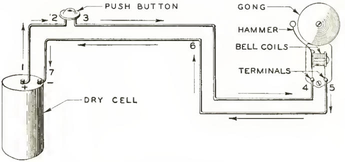


Fig. 8. An Electrical Bell Circuit

of wheel *2*. The push button shown takes the place of the knot tied in the string. The dry cell furnishes the power and voltage for forcing the electric current through the bell circuit. The pressure of this dry cell is about 1.5 volts, but it cannot force any electrical current through the circuit until the push button is pressed and

there is a complete electrical circuit, any more than you could transmit the power from wheel *1*, Fig. 7, to wheel *2* until you pulled the string tight and tied a knot in the string.

When the push button, Fig. 8, is pressed, current flows from the positive (+) terminal of the dry cell to the copper wire *1*, through wire *2*, push button, and wire *3*, to terminal *4* of the bell. Then the current flows through the coils of the bell to terminal *5*, through wires *6* and *7*, to the negative (−) terminal of the dry cell. The flow of electric current through the bell coils causes the bell to ring. This flow of electric current through the wires and bell, Fig. 8, cannot be seen but its action can be compared to the travel of the knot in the string, Fig. 7. When the handle on wheel *1* is turned, the knot in the string will move over the top of wheel *2*, around it, and back to the under side of wheel *1*, then over the top of wheel *1*, and on to the top of wheel *2*, and keep on traveling around these wheels as long as the handle is turned. The faster the wheel is turned, the faster the cord will travel around this circuit. The flow of electric current through the circuit is very rapid and much faster than the movement of the cord when the wheel is turned at the highest speed.

The electric current will continue to flow and ring the bell, Fig. 8, until the circuit is opened or broken by releasing the push button. The flow of current can be stopped by opening the circuit at any point, by breaking the wire at any place, or by removing the wire from any one of the terminals of the dry cell, the push button, or the bell. The opening of the electrical circuit will correspond to cutting the string in Fig. 7. It does not make any difference whether the string is cut at the knot, near the wheel *2*, or at wheel *1*. Likewise in the electrical circuit, the flow of current stops just as soon as the electrical circuit is opened or broken and it does not make any difference where this break occurs in the circuit. Whenever a break occurs in the wires, the defect is called an "open circuit." As soon as a break occurs in an electrical circuit, the flow of current stops because the resistance of the air between the ends of the wire or circuit is so great that the voltage cannot force any current through this high resistance. When an electrical circuit is broken on purpose, that operation is called "opening the circuit."

TWO ELECTRICAL CIRCUITS

The wheel *1*, Fig. 7, can be used to operate two gongs at the same time, or it can be made to operate first one gong and then the other. The method of connecting the wheel by cords is shown in Fig. 9. When knot *A* in the string is pulled up tight and wheel *1* is turned by the handle, the knot will move around wheel *1* to pulley *2*, turn pulleys *3* and *4*, and keep traveling in this path as long as the handle on wheel *1* is turned. When pulley *3* turns, it rings gong *1*. Then if it is desired to ring both gongs *1* and *2* at the same time, knot *B* is tightened, which will cause the string

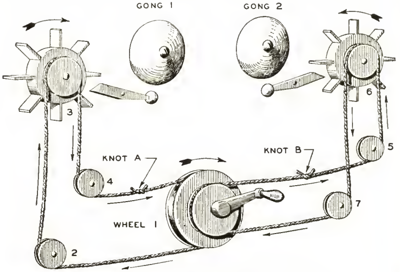


Fig. 9. A Method of Operating Two Bells from One Place

to travel over pulleys *5*, *6*, and *7*, causing gong *2* to ring. Either gong *1* or gong *2* will stop ringing at any time when the handle is being turned, if either the cord containing knot *A* or the cord containing knot *B* is cut.

Just as two gongs can be operated from one wheel, Fig. 9, so can two electrical bells be operated from the same source of electric power—which may be a dry cell. Fig. 10 shows the method of connecting a bell and a buzzer to one dry cell. The only difference between a bell and a buzzer is that a buzzer does not have a hammer, and it gives off a small buzzing sound when operated.

When the push button *A*, Fig. 10, is pressed, current will flow from the positive (+) terminal of the dry cell through wire *1* to wire *2*, through push button *A*, through wire *3* to terminal *4*, through the bell to terminal *5*, and back to the negative (−) terminal of the dry cell. The current will continue flowing through this path or electrical circuit until the circuit is opened by releasing the push button, which allows the two contacts to separate. When push button *B* is pressed, current flows from the positive (+) terminal of the dry cell to wire *12*, through push button *B*, through wire *13* to terminal *14* of the buzzer, through the buzzer to terminal *15*, and the wire connected to the negative (−) terminal

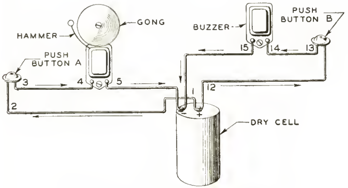


Fig. 10. A Dry Cell Operating a Bell and a Buzzer

of the dry cell. The flow of current through the buzzer will cause it to operate and give a buzzing sound, which it will continue to do until the circuit is opened by releasing the push button *B*. Thus the flow of electric current through this electrical circuit may be compared to the movement of the string over the wheels, Fig. 9.

SEVERAL ELECTRICAL CIRCUITS

The wheel with the handle, Fig. 7, may have several cords around it and operate several wheels and gongs at the same time. In Fig. 11 there are three cords around the wheel with the crank, and when the crank is turned, the three gongs will ring at the same time. In some cases, the cords may cross and operate the notched wheel in the opposite direction, as with gong *3*.

In every case, the cord makes a complete circuit and travels round and round again over the same path, which is similar to going round and round a circle.

Electric bells can be operated by electricity in a somewhat similar manner. Several electric bells can be wired and operated by electricity from the same source of power, which is usually a dry cell or several dry cells, just as the three gongs in Fig. 11 were operated from one crank. A wiring diagram showing how three bells can be wired and operated from a dry cell is shown in Fig. 12. In this diagram, as in all wiring diagrams, the wires are represented by lines. When one wire is spliced or joined to another wire, the connection is indicated by a black dot where the wires cross or join, as at *A*, *B*, *C*, etc. In a diagram, when two lines cross and there is not a black dot at that point, it means that

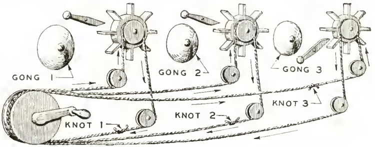


Fig. 11. A Method of Operating Three Bells from One Source of Power

one wire is back of the other wire, and that they do not touch each other and are not connected or joined together.

In electrical work it is not necessary to run two wires directly from the dry cell to each bell, as was the case with the crank wheel, cords, and gongs in Fig. 9. The electric current from the battery to two or more bells can flow through the same wires for part of the distance.

Fig. 12 shows how three bells may be operated from one dry cell. The current of the three circuits uses the same wire between the plus terminal and point *A* and between point *F* and the minus terminal. When push button *1* is pressed, voltage or pressure of the dry cell will force an electric current from the positive terminal of the dry cell, through the wire to splice *A* and bell *1*, through the bell to the left-hand terminal, through the push button, through

the wires *D*, *E*, and *F*, on to the negative (−) terminal of the dry cell, making a complete circle or circuit. Electric current will continue to flow through this circuit and ring bell *1*, until the finger is removed from push button *1*, which allows a spring to separate the two contacts and open the circuit.

The voltage of the dry cell will also have a tendency to force the electric current from the positive (+) terminal of the dry cell through the wire to *A*, then to *B*, through the terminals of bell *2*, on to the push button *2*. However, there is a gap or an air space in push button *2*, and the resistance of air is so great that the voltage of the dry cell cannot force any electric current through this resistance. Since there is not a complete electrical circuit, there cannot be a flow of electric current through bell *2* and it cannot ring.

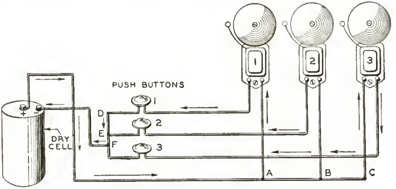


Fig. 12. A Method of Operating Three Bells from One Dry Cell

However, just as soon as push button *2* is pressed, you have a complete electrical circuit and the current will flow and ring bell *2*. The electric current will then flow from the positive (+) terminal of the dry cell through the same wire as the current flowing to bell *1*, to the splice *A*, then on to *B*, through terminals of bell *2*, through the push button *2* to *E*, then through the same wire as the current returning from bell *1* and push button *1*, to *F* and on to the negative (−) terminal of the dry cell. When push buttons *1* and *2* are pressed at the same time, you have an electric current flowing through the circuit as traced for bell *1*, and also have an electric current flowing through the circuit as traced for bell *2*. The amount of current flowing from positive (+) terminal of the dry cell to *A*, Fig. 12, and from *E* to

the negative (−) terminal of the dry cell is obtained by adding together the number of amperes of current flowing through bell *1* and the number of amperes of current flowing through bell *2*.

The voltage of the dry cell will also try to force electric current from the positive (+) terminal of the dry cell through the wires to *A*, then to *B*, then to *C*, through bell *3*, on to the lower contacts of push button *3*. There is a gap or air space between the upper and lower contacts of push button *3*, and this resistance is so high that it prevents the voltage from causing a flow of current through bell *3*. However, just as soon as push button *3* is pressed and the circuit is completed, you will have a flow of current through bell *3* which will ring that bell. This flow of electric current is from the positive (+) terminal of the dry cell, through the same wires as the current flowing through bells *1* and *2*, then to *C*, through bell *3*, through the contacts of push button *3* to *F*, then through the same wire as the current returning from push buttons *1* and *2*, to the negative (−) terminal of the battery. If push buttons *1*, *2*, and *3* were all pressed at the same time and the dry cell had sufficient current and voltage, it would force an electric current through the three bells at the same time and cause all three bells to ring. The flow of current through each bell and push button would be just the same as it was when each particular push button was pressed. The total amount of current in amperes flowing from the positive (+) terminal of a dry cell to wire *A* and from wire *F* to the negative (−) terminal of the dry cell is obtained by adding together the number of amperes of current flowing through bell *1*, the number of amperes of current flowing through bell *2*, and the number of amperes of current flowing through bell *3*.

In Fig. 12 the electric current is flowing through bells *1* and *2* in the opposite direction through bell *3*. With most types of electrical apparatus it does not make any difference in which direction the current flows through the apparatus. With an electric doorbell or buzzer it makes no difference in which direction the current flows through the bell or buzzer. Likewise it makes no difference whether the push button is connected in the wire going from the positive (+) terminal of the dry cell to the bell or whether it is connected in the wire going from the negative (−) terminal.

CONNECTING VOLTMETER

The voltage of an electrical circuit is determined by connecting the two terminals of the voltmeter to the two places on an electric circuit between which it is desired to know the voltage. The voltage of a dry cell is determined by touching the end of the wire fastened to the positive (+) terminal or binding post of the voltmeter to the positive (+) terminal of the dry cell and touching the other end of the wire fastened to the negative (−) terminal of the voltmeter to the negative (−) terminal of the battery, Fig. 13. These wires are usually referred to as "voltmeter leads" or just "leads" because they are used to lead or carry the current from the battery to the voltmeter.

If bare copper wire were used for the leads to connect the voltmeter to the dry cell, Fig. 13, it would be necessary to be very

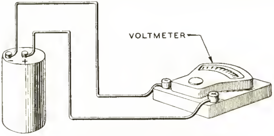


Fig. 13. Measuring the Open-Circuit Voltage of a Dry Cell with a Voltmeter

careful to keep the two wires apart and not allow them to touch each other, otherwise the dry cell would be short-circuited. For convenience, in order to make the leads easy to handle, they are covered with insulation, which is usually rubber, and instead of using a solid wire, a stranded wire is used. A stranded wire has several very small wires twisted together, and these wires are then covered with insulation.

The voltage reading obtained from the dry cell, Fig. 13, is called the "open circuit" voltage, because the dry cell is not delivering any current to an electrical circuit. The voltage reading obtained from the voltmeter when the push button, Fig. 14, is pressed and an electric current is flowing through the wire and ringing the door bell is called the "closed circuit" voltage. The "closed circuit" voltage reading of a dry cell, storage battery, or electric

generator is usually less than the "open circuit" voltage reading.

The three push buttons shown in Fig. 12 can be pressed at the same time and the three bells will ring. The direction of the flow of current is shown by the small arrows alongside of the line

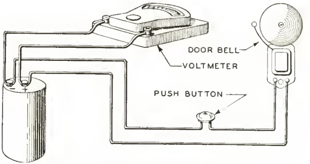


Fig. 14. Measuring the Closed-Circuit Voltage of a Dry Cell with a Voltmeter

representing the wiring, Fig. 15. The voltage between any two wires is measured by connecting or touching the voltmeter leads to the wires.

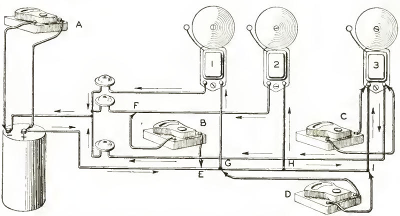


Fig. 15. Measuring Voltage at Different Places in a Bell Circuit

The voltmeter A, Fig. 15, has its leads connected to the positive (+) and negative (−) terminals of the dry cell. This meter will indicate the voltage or electrical pressure of the dry cell.

The voltmeter *B*, Fig. 15, will show the voltage between the two wires to which its leads are connected. This voltmeter shows the voltage between points *E* and *F*, Fig. 15.

The voltmeter *C* has its leads connected to the terminals of bell *3* and will indicate the voltage at the terminals of the bell. It is this voltage that forces an electric current through the winding or "works" inside the bell.

The reading of voltmeter *C* will be lower than the reading of voltmeter *A*. The reason is because some of the voltage of the dry cell will be used in forcing the electric current through the wires from the positive (+) terminal of the dry cell to one terminal of the bell and from the other terminal of the bell to the negative (−) terminal of the dry cell. A copper wire is a good conductor but it has a small amount of resistance which will "use up" some of the voltage when a current flows through the wire.

The amount of voltage "used up" in forcing an electric current through a wire can be obtained with a voltmeter. The leads of the voltmeter are connected to two points on the wire, as *G* and *I*, Fig. 15, and the amount of voltage "used up" is shown by voltmeter *D*. The reading of voltmeter *D* will be very small as compared to the readings of voltmeters *A*, *B*, or *C*.

The most important thing to remember about a voltmeter is that it always measures the voltage or electrical pressure between the two points to which the voltmeter leads are touched or connected.

CONNECTING AMMETER

The outside cover or case of an ammeter is very similar to and sometimes is the same as that of a voltmeter. The ammeter usually has larger terminals or binding posts than a voltmeter. An ammeter indicates or shows the amount of current in amperes flowing through a circuit, just the same as the flowmeter indicates the amount of water flowing through the pipe.

The method of connecting an ammeter in order to measure the current flowing in the bell circuit, Fig. 8, is shown in Fig. 16. Instead of connecting the ammeter in on the wire leading from the positive (+) terminal of the dry cell to the bell, Fig. 16, it could have been connected in on the wire going from the bell to the negative (−) terminal of the dry cell. The ammeter

would then measure the current returning from the bell to the dry cell, which would be the same amount of current in amperes as when the meter is connected as in Fig. 16.

The method of connecting ammeters in the electrical circuit in Fig. 12 is shown in Fig. 17. In this illustration when

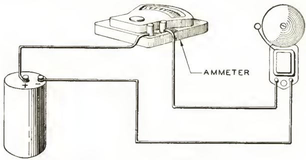


Fig. 16. Connecting Ammeter in Bell Circuit

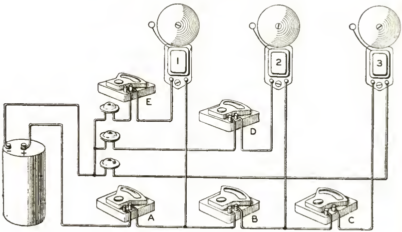


Fig. 17. Measuring Current in Different Parts of Bell Circuits

the push buttons are pressed, ammeter *A* will show the total current in amperes flowing from the dry cell to the three bells. Ammeter *B* will show the amount of current flowing to bells *2* and *3*. Ammeter *C* will show the amount of current flowing to bell *3*. Ammeter *D* will show the amount of current flowing, or returning, from bell *2* to the dry cell. Ammeter *E* will show the amount of current flowing, or returning, from bell *1*.

In Fig. 17, five ammeters are shown connected in the electrical circuits. They can be used to measure the current in the different parts of the electrical circuit at the same time or, as is usually done, only one ammeter is used and it is connected like the ammeter at *A*, Fig. 17, and the amount of current in amperes is read from the meter. Then the wires connected to the terminals of the ammeter are removed and twisted together, and the ammeter is connected to the wires as at *B*, Fig. 17. Then after the reading of the current in amperes at *B* is obtained from the meter, the wires are removed from the terminals of the ammeter and joined together. The ammeter is then connected to the next place where it is desired to know the amount of current flowing through the wires at that place. This method is kept up until the current in all the desired places has been measured.

An ammeter must always be connected in the circuit so that the current to be measured can flow through the meter. Never connect an ammeter across the two wires of a circuit like a voltmeter, because if you do you will ruin and spoil the ammeter so you cannot use it again.

REVIEW QUESTIONS

1. What is an *electrical circuit?*
2. What are the two requirements necessary to establish a flow of electrical current?
3. What is a *polarized device* and what care must be exercised in connecting it to a circuit?
4. For the purposes of discussion in this book, which terminal of a cell, battery, or generator is considered to have the higher potential? What is the direction of current flow?
5. What does the expression "opening the circuit" mean? What occurs?
6. Draw a simple diagram indicating the method of connecting one bell, one push button, and one dry cell.
7. In the diagram for question 6, indicate the *polarity* of the dry cell, and trace the direction of current flow through the circuit.
8. What is an open-circuit voltmeter reading?
9. What precaution must you observe in connecting an ammeter to a circuit?
10. Why is the voltage reading which is taken at the bell terminals in question 6 less than the voltage reading taken directly across the terminals of the dry cell?

APPLICATIONS TO INDUSTRY

1. Draw the symbol for a single dry cell. For a battery. Indicate the *negative* and *positive* terminals on each.

2. If a voltmeter is connected to a circuit with its polarity reversed, what will happen?

3. How would you connect a bell with its push button, and a buzzer with its push button, both to a single dry cell to operate independently of each other? Draw a diagram.

4. Take the bulb out of your flashlight and inspect the markings on its base. What are they? How many cells are there in the battery case? What relationship is there between the markings on the bulb base and the number of cells?

5. When you connect a push button to operate a bell, does it make any difference whether the push button is located in the negative lead or positive lead? Why?

PRIMARY AND STORAGE BATTERIES

How Batteries Are Made. Electrical pressure and electric current can be generated by chemical action. The device with which this pressure and current are produced is called an *electric cell*. Two or more cells connected in series or parallel form an *electric battery*.

If two electrical conductors made of unlike materials are placed in a liquid so that they do not touch each other, and if the liquid is such that it will act chemically on one of these conductors, an electrical pressure will be set up and current will be produced, provided these conductors are joined together by an outside conductor. The liquid in which the conductors are placed is called the *electrolyte*. It will be found that one of these conductors will have a higher potential than the other one. This conductor is called the *positive plate*, whereas the other conductor is the *negative plate*.

The amount of pressure generated by this chemical action will depend upon the materials of the plates, or conductors, and the nature of the electrolyte. Neither the size of the plates nor the distances by which they are separated will have any bearing upon the electrical pressure which they generate. Therefore to make an electric cell, you must have two plates made of different materials, immersed in a solution which will act chemically upon one of the plates.

THE PRIMARY CELL

If the cell is the type which, when it ceases to produce current, must be renewed by replacing a used-up plate and renewing the electrolyte, it is called a *primary cell*. If, on the other hand, its renewal is brought about by passing a charging current through it from an outside source of supply, then it is called a *secondary*, or *storage cell*.

Primary cells, or those which must be discarded or which require the replacement of parts when they cease to produce current, are now grouped into two classes, *wet cells* and *dry cells*.

Wet Primary Cells. These cells were the first electric batteries.

They generated the first electric currents, and were in existence before mechanical generation of electricity was thought of or attempted. It was with cells of this type that men performed all of those important experiments which revealed the underlying principles of electricity. They were crude affairs, and they were used only in the earlier laboratories. They played no part in industry; indeed they were scarcely known to exist, until the advent of the telegraph. Their importance grew and expanded with the growth of our communications systems.

It is interesting to note that the battery used in the earlier laboratories was particularly adapted to telegraphic work. The construction of the telegraphic circuit called for a continuous flow of electricity, except during the sending of the message. In sending the message, the circuit was broken intermittently to send the dots and dashes of the code along the lines.

The Closed-Circuit Cell. Present-day cells which are adapted for this form of use are a type of the wet primary cells and are called *closed-circuit cells.* To be suitable for closed-circuit work, which involves supplying continuous current for a circuit, a cell must be one that is not easily polarized. By polarization, we mean the gradual collection of hydrogen bubbles from the electrolyte about the positive electrode of the cell, until a film of insulation is deposited around that electrode. While these early cells had some tendency toward polarization, it however was not as pronounced in these cells as in some of the later types. Polarization causes a high resistance to be set up in the cell and battery, and thus shuts down its current flow. It was discovered later that this polarization could be reduced by introducing into the cell, around the positive electrode, some chemical which would produce oxygen which, in turn, would blend with the hydrogen bubbles to become water. This oxygen-producing substance is called a *depolarizer.*

The original closed-circuit cell was composed of zinc, copper, and diluted sulphuric acid. In the earlier cells the copper and zinc electrodes were in the form of bars or plates. Later, as their manufacture was standardized, they were made with cast zinc electrodes of a shape known to the trade as *crowfoot.* A picture of this cell is shown in Fig. 1. The zinc electrode is cast with a projection so that it hangs in the electrolyte from the edge of the wide-mouth glass jar

that forms the case of the cell. This is the *negative* electrode of the cell, to which is attached the negative terminal. The positive electrode is made of copper strips, of which several are riveted together, and to which a length of connecting wire, long enough to reach the zinc electrode of the next cell, is attached. Before introduction into the battery jar, these copper strips are pulled apart into the shape of a crow's foot, which rests upon the bottom of the jar.

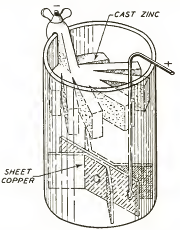


Fig. 1. A Closed-Circuit or Gravity Cell

This cell's able performance in the closed circuit of the telegraph rests upon the dual action of the electrolyte used. This electrolyte is a simple solution of copper sulphate crystals and water. The copper sulphate crystals, commonly known as blue vitriol, copper vitriol or blue stone, are produced by the action of sulphuric acid on copper and copper oxide. A one-gallon glass jar forms the case for the commercial size of this cell. The copper and zinc elements are placed in position and the jar is filled with clear water. Two pounds of copper sulphate crystals are added. In time, the electrolyte separates into two solutions, the one at the top being clear and the one at the bottom being blue. It is this separation that gives the cell its ability to perform on closed-circuit work, for the chemical action is such that rapid and almost complete depolarization is maintained. Since the separation of the electrolyte is maintained by gravity, the cell also is known as a *gravity cell.* This gravity cell is a form of the wet primary cell, known for a long time in the laboratories as the Daniell cell.

The Open-Circuit Cell. As the telephone was perfected, and as its use spread, another type of wet primary cell came into commercial use. The telephone circuit is designed so that current is flowing through the lines only while conversation is actually taking place. Therefore, it is not necessary to use a battery designed to provide such complete depolarization. The telephone circuit is in actual use for such short periods that there is ample time for the battery to depolarize itself when not in use. Also, the gravity cell has a low current output, whereas a heavier current is required for telephone work.

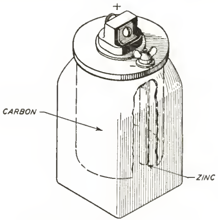


Fig. 2. An Open-Circuit Wet Primary Cell

A cell previously had been developed, using zinc and carbon for electrodes, and a solution of ammonium chloride as an electrolyte which functioned better in telephone work. It had not been developed for telegraphic work because it could not be used continuously, but it was well adapted for the telephone circuit. It was found that it could be used in much smaller sizes, and a size was adopted whereby the jar could accommodate about a quart of electrolyte.

The carbon, or positive, electrode is usually cylindrical in form, while the negative electrode is a cast zinc rod. This cell is shown in Fig. 2.

The electrolyte is formed by adding about a half-pound of ammonium chloride, known to battery men as sal ammoniac, to the battery jar when it has been filled to nearly two-thirds of its capacity with clear water.

This cell has very good recuperative powers when it is allowed sufficient time for rest. However, if it is to be used on circuits that do not permit the long rest periods, as in telephone work, further provision must be made for depolarization.

A cell was developed from the above described cell, known as the Leclanche cell, which could be used for somewhat longer periods. About the only difference between the two cells was that the Leclanche cell had its carbon electrode surrounded by a mixture of powdered carbon and manganese dioxide which the other cell lacked.

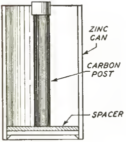


Fig. 3. Zinc Can and Carbon Post of a Dry Cell

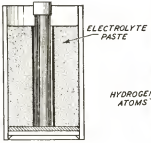


Fig. 4. Zinc Can Filled With Electrolyte Paste

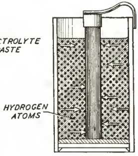


Fig. 5. Direction of Hydrogen Atoms in Dry Cell

The manganese dioxide gives off oxygen, which combines with the hydrogen bubbles, changing into water and thus depolarizing the battery.

It was from this Leclanche cell that our modern dry cell was formed. This dry cell has displaced the wet cell on the commercial market.

Dry Cells. A dry cell is not really *dry*, but its electrolyte is in the form of a paste containing sufficient moisture for chemical action. Dry cells are primary cells, of course, and they must be replaced with new ones when they cease to supply current. They cannot be recharged.

In these cells, zinc is generally used as the negative electrode, and this is constructed in the form of a cup, or can, which forms the outer wall of the cell, as shown in Fig. 3. This can will hold the other active elements which make up the complete cell.

The positive electrode is usually a conductive carbon rod, located at a central point in the zinc can, at equal distances from all

points on the zinc wall. It is separated from the bottom of the can by an insulating washer, or disk, Fig. 3.

The electrolyte of these cells usually is a mixture of sal ammoniac and zinc chloride, held, or absorbed, in a gelatinous or spongy material in the form of a paste. This electrolyte paste, Fig. 4, is not spillable; nevertheless, care must be taken in sealing the cell so that moisture loss will not occur.

Since action in these cells depends upon the chemical attack of the electrolyte upon the zinc case of the cell, the zinc is gradually

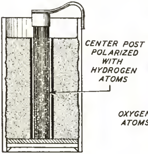


Fig. 6. A "Polarized" Cell

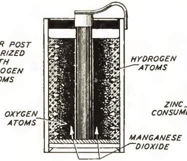


Fig. 7. Action of Manganese Dioxide

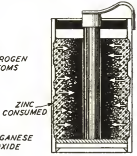


Fig. 8. Result of Long Use of a Cell

dissolved. With the consuming of the zinc, hydrogen atoms are released to gather around the carbon post, Fig 5, in the form of bubbles, which increase the internal resistance of the cell until this post is practically insulated from further passage of current. When this occurs, the cell is said to be *polarized.* Fig. 6 shows this condition.

Certain agents, called depolarizers, are used to overcome this condition. One of these is oxygen-producing manganese dioxide, packed into the cell between the electrolytic paste and the carbon post, as shown in Fig. 7. Oxygen atoms released by the manganese dioxide attract and absorb the hydrogen atoms. Thus, the hydrogen film is prevented from collecting upon the carbon post.

As the electrolyte attacks the zinc in this production of current, the zinc is gradually eaten away. See Fig. 8. This process will continue until the zinc becomes so thin that holes appear in its surface. Through these holes the air will enter the cell and moisture will be lost from the electrolyte. The electrolyte will dry until further chemical action is impossible, and the cell is dead.

At first, manufacturers had difficulty in sealing the moisture in these cells. Present-day manufacturing processes however are so perfect, and the cells so well sealed that trouble rarely occurs from this cause. The present-day cells are so well constructed that the time they are in stock on the dealer's shelves does not materially detract from their value when put into use. Nevertheless, many manufacturers date their cells, so the consumer may be sure that he is getting one from a fresh stock.

If a dry cell has been on a severe short circuit, or if it is continued in service beyond its normal life, leaks are likely to occur through the sealing material or the case itself. The solution which escapes through these leaks may be detrimental, since it is a rather strong solution of zinc chloride, which has a pronounced caustic effect upon metals. You may have noticed how a run-down battery will ruin a flashlight case if it is allowed to remain within it for a long time after the battery is exhausted.

Voltages of Dry Cells. All dry cells are rated at 1.5 volts. This, as we have said, is determined by the materials used in the electrodes and the type of the electrolyte. Of course, this voltage is not maintained throughout the life of the cell. The voltage of the cell, and even its useful life, is largely determined by the use to which it is put. Dry cells are not expected to take the place of mechanically generated electricity. They are intended to supply a type of service where, for one reason or another, it is more convenient to have a small direct-current supply, or where the supply must be portable. The ordinary dry cell is designed and intended only for intermittent service; that is, to be used for short periods, and rested for longer periods. Thus used, dry cells will give long and faithful performance.

If you will notice the voltage rating of a flashlight bulb for a one-cell battery, you will find it given as 1.2 volts. This should suggest to you that the voltage throughout most of the life of the flashlight cell is accepted by the lamp manufacturers as somewhere near 1.2 volts.

Let us take the ordinary large-size flashlight cell, which is identified by the Bureau of Standards as a Type "D" cell, as a typical example of dry-cell voltage. If the cell is favored during most of its life, as to current drain, by use for short periods only, it will show a nearly uniform voltage drop from its initial voltage of about 1.5

volts for about the first third of its life. At this time the cell voltage should approximate 1.2 volts. This it will maintain rather evenly for the next one-third of its life period. From then on, its voltage will decline at about the same rate as during the first one-third period. This decrease in voltage values will show a voltage of, or near, 1.2 for most of the useful life of the cell.

Generally speaking, the larger the cell, the longer its life, since in a large cell there is more zinc to be acted upon, making its life longer. Some uses to which dry cells have been put require that

Fig. 9. Interior Construction Showing Unit Cells in a Radio "B"-Battery
Courtesy of Burgess Battery Company, Freeport, Illinois

batteries be light in weight and small in size. To make cells within these limitations, naturally results in some sacrifice of battery life. Usually, however, the loss in battery life is more than compensated for by the convenience of the device. For instance, it is sometimes more convenient to carry a small flashlight than to carry a large one, or to be burdened with an electric lantern.

While individual cells have a 1.5 voltage rating, groups or batteries of them may have much higher ratings. Some of these, such as radio "B" batteries, carry ratings as high as 90 volts. These usually are made up of groups of unit cells each having a voltage of 1.5, connected in series. Many manufacturers use type "D" cells as the unit cells in "B" battery construction. Fig. 9 shows how one company builds its radio "B" batteries with this unit cell construction.

A radio set demands of its "B" battery that it deliver a high potential with a very small current drain. Therefore, small cells can be incorporated into it satisfactorily. You must bear in mind, however, that while it is possible to combine enough of these batteries to create a potential of 110 volts, you could not expect to power an ordinary residence light globe with this current source, with satisfactory results. These unit cells are not designed for a current drain that heavy. The battery would soon become exhausted, and its use would be expensive.

Sizes of Dry Cells. Regular flashlight cells are manufactured in three sizes. There is the small cell designed for the pen type of flashlight, and an intermediate size for flashlights between these two in

Fig. 10. Three Sizes of Flashlight Dry Cells
Courtesy of Burgess Battery Company, Freeport, Illinois

size. Some manufacturers build "D" cells for heavy-duty industrial use, in addition to the three ordinary sizes of "D" cells. These, however, are not recommended for general flashlight service. Fig. 10 illustrates the three sizes. Since each manufacturer gives the cells his own numbers, you cannot use the number on your old battery to designate the size of a new one of different make.

Perhaps the first dry cell to be made in quantities and sold extensively was a dry cell six inches high and two inches in diameter. This was known as a No. 6 cell, and was built and described as such by all companies. It was widely used for ignition and telephone work, quickly replacing the wet cells in these fields. It is available in stores at the present time, and has many uses. There are two types of this cell. You can buy a No. 6 *ignitor* for ignition work, or a special No. 6

Fig. 11. No. 6 "Ignitor" and No. 6 "Long Life" Dry Cells
Courtesy of National Carbon Company, Inc., New York City

long life cell adapted for telephone work. Fig. 11 shows both types.

It was the radio, however, that called out the wide variations in shapes, styles, and sizes of dry batteries which we see on the market today. Each manufacturer of battery radio sets has called upon the battery makers to produce a battery to fit the particular requirements of his product. Consequently, batteries now differ in design, to the degree that it would be almost impossible to compile a descriptive list that would be complete, or that would remain up-to-date for any length of time. We can say, however, that the lists usually consist of groupings of unit cells.

The new camera type pocket radio, for instance, demanded a very small and compact "B" battery of extremely light weight, and battery manufacturers have met the demand with a battery that is amazingly efficient, considering its size. For the "A" battery supply, most of these small sets make use of type "D" flashlight cells.

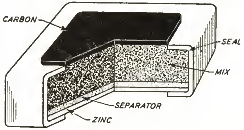


Fig. 12. Unit Cell Construction of a "Layer-Built" Battery

The company that produces the *Eveready* battery, however, has discontinued the use of the flashlight cell as a unit cell in the construction of "B" batteries for portable radio sets. The company has brought out what it designates as a *layer-built* battery for this work. This type of construction uses the same materials that make up any dry cell. The difference is in the design. Both carbon and zinc electrodes are in the form of plates, Fig. 12, instead of a rod and cup. These plates are stacked, with the electrolyte mixture between them, into 22½-volt units which in turn are grouped to make the batteries of required voltages.

Other special batteries on the market are those designed for electric lanterns, and those made for blasting purposes.

LEAD-ACID STORAGE CELLS

In the type of cell known as the *storage* cell, the cell is reconditioned for further service by passing a current through it, in the opposite direction to the current flow of the cell. This renews the charge. Since no part of the cell is replaced when renewing this charge, this is not a primary cell.

The term *storage*, used for this cell, is misleading, however, for it certainly does not *store up* electricity. However, the current passed into this battery causes a chemical action which will return electricity to the line when it is again allowed to do so; therefore the effect is the same. The action of the battery in producing current is not greatly different from the action of the primary cell. You might think of it as being designed from materials selected for their ability to redeposit, on charge, the active materials which have been removed during the discharge period. Even this is not an exact description of the chemical action which takes place in this cell during the discharging and recharging operations. It would be somewhat more exact to say that certain changes occur in the chemical composition of the electrodes, or plates, which produce this renewal of current charge.

This secondary, or storage, battery is thought to have had its origin shortly after 1850, when a man named Planté produced a cell consisting of two plates of metallic lead immersed in an electrolyte of dilute sulphuric acid. In this experimental cell, the acid soon caused a thin layer of lead sulphate to form on each plate, and this stopped the current flow. Planté experimented with charging and

discharging this simple cell until he discovered that its action was steadily improving. Further investigation disclosed that the surfaces of these lead plates were undergoing a chemical change. He found that his positive plate was now covered with a coating of peroxide of lead, while the coating which had collected upon the surfaces of the negative plate was pure lead in a spongy form. From these simple experiments the Planté-type of plate was constructed. This is probably our best storage battery plate, except that it still has to be *formed*, or brought into condition, by methods similar to those which Planté used in his first experimental cell. This is a

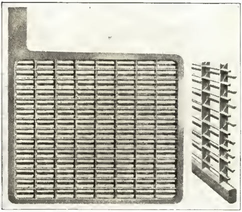


Fig. 13. Grid Construction of a Storage Battery Plate for Holding the Active Material
Courtesy of Gould Storage Battery Corporation, Depew, N.Y.

tedious and expensive process; one which few manufacturers care to undertake.

Shortly after Planté had invented his type of plate, a man named Faure suggested a plan to put the peroxide of lead and the spongy lead directly upon the surfaces of the plates, thus eliminating much of the time and expense involved in their formation. He proposed to *paste* these active materials upon the surface of the plates.

The plate known as the Faure-type is now widely used in storage battery construction. It is, of course, improved over the one Faure himself designed.

The present manufacturing method is to cast a plate grid, similar to the one shown in Fig. 13, from a mixture of pure lead and

antimony. This gives the plate structural strength and provides recesses into which the active materials, in paste form, can be forced.

In the primary cells, two entirely different metals are used in the electrodes. In the storage cell, two dissimilar compounds of the same metal are used. This metal is lead. Lead peroxide forms the active material on the positive plate. A completed positive plate is shown in Fig. 14. The color of the active material is dark brown. Spongy lead makes up the active material of the negative plate, and its color is that of metallic lead or dark gray. The plate construction is the same as in Fig. 14. The electrolyte is dilute sulphuric acid.

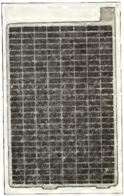


Fig. 14. A Pasted Storage Battery Plate
Courtesy of Gould Storage Battery Corporation, Depew, N.Y.

During discharge, chemical action within the cell is such that the *unlike* lead compounds on the positive and negative plates tend to become *like* compounds. This is brought about by the chemical action in the electrolyte, in which it gives up to the positive plate part of its sulphate, thus tending to change the lead peroxide into lead sulphate. At the same time, part of the sulphate from the electrolyte combines with the spongy lead of the negative plate, tending to change it into lead sulphate. Now if it were possible to completely discharge a storage cell, all the sulphuric acid would be withdrawn from the electrolyte by this process, until the solution consisted of nothing but water. Discharge of a cell cannot be completed thus far. However, it can be carried to the point where so much of the acid is withdrawn from the electrolyte that it will freeze.

When a battery is placed on its renewing charge, this process is reversed. Sulphate is removed from the plates and the acid is restored to the electrolyte. A fully-charged battery will have enough acid in the electrolyte to prevent freezing.

Testing the Battery by Measuring the Electrolyte. Since acid is removed from the electrolyte as a battery is discharged and replaced during the charging period, we can arrive at some idea of the condition of the battery, or the amount of charge it holds, by measurement of the electrolyte.

Such liquids are measured by comparing their weight with that of water. The weight of water is taken as a basis of measurement, and given a value of 1. The instrument for making this measurement is called a *hydrometer*. It consists of a small, weighted glass float with a scale. It will float in pure water with this mark of 1 at the water level. The addition of acid to the water will increase the density of the liquid, and the float will rise in the liquid as the density is increased. On this hydrometer, a discharged battery will probably show a reading of 1.150, which is often read by the practical man as eleven fifty (1.150). A completely charged battery would register as high as 1.280. This is shown in Fig. 15. This process is known as measuring the specific gravity of a liquid. This change in the specific gravity of the electrolyte is an accurate indication of the condition of the battery with respect to its ability to furnish current; therefore it is the most accurate measurement of the battery's condition.

Sulphation. A battery cannot function without a certain amount of sulphation. A normal amount of sulphation produces the change in the chemical characteristics of the plates of a battery, and it is absolutely necessary in the production of current. As long as sulphation can be controlled, it is not harmful. It is when the sulphate can no longer be removed from the plates by chemical action that it becomes troublesome. Excess sulphation is evidenced in several of the following ways: An excessive amount of paste may be loosened from the plates, separators may become clogged, and plates may become buckled.

Extreme sulphation is often caused by allowing the battery to remain in an uncharged condition, or by continuous low charging. There are other conditions which will cause excessive sulphation. Indeed, it might be thought of as old age, slowly overcoming a battery

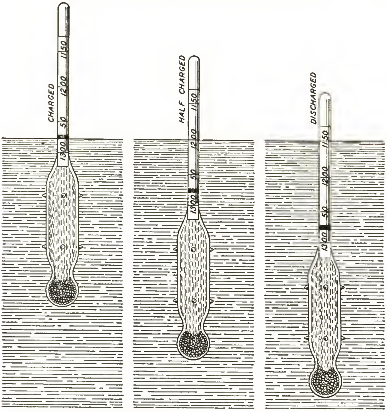


Fig. 15. Position of a Hydrometer in the Electrolyte of a Fully-Charged, Half-Charged, and Discharged Lead Battery

that has been in service for a long time. When extreme sulphation occurs, the life of the battery is over. No amount of charging will restore it when it is in this condition. Care and attention may postpone extreme sulphation, but once it is complete there is no cure.

Assembling the Cell. Plates are assembled on grid-posts by a welding process known as *lead burning*. This is done with a small torch having a tiny flame, since it does not take much heat to melt lead. All the positive plates to be used in a cell are grouped together to form the positive group, and the negative plates are assembled to form the negative group. In the final assembling of these two groups, the positive plates are inserted between the negative plates.

The positive and negative plates of this assembly are kept from

contact with each other by *separators*. Fig. 16 shows a typical separator. The complete assembly of these two groups of plates and their separators is shown in Fig. 17.

Fig. 16. A Wood Separator
Courtesy of Gould Storage Battery Corporation, Depew, N.Y.

Separators must be made of insulating material. They must also be somewhat porous, to give the electrolyte access to the surface of the plates. Separators are commonly made of wood, although some manufacturers make use of separators made from rubber.

Notice, in Fig. 16, that there are grooves upon the surface of the separator. The side of the separator containing these grooves is placed so that it lies against the positive plate, with the grooves in a vertical position. During the life of a battery, some shedding of the

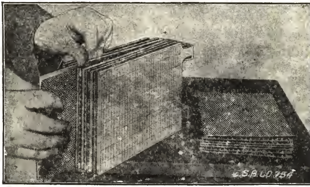


Fig. 17. Inserting a Separator Between the Positive and Negative Plates When Assembling a Battery
Courtesy of Electric Storage Battery Company, Philadelphia, Pa.

active material from the face of the positive plate is occurring. These grooves are provided in the separator so that this material may fall through them to the bottom of the battery case. All jars or cases for these lead-acid cells must be provided with ample open space below the bottom level of the plates, to accommodate this sediment, or *sludge*, as it is sometimes called. This sediment is a form of metal, and therefore a conductor of current. If it accumulates

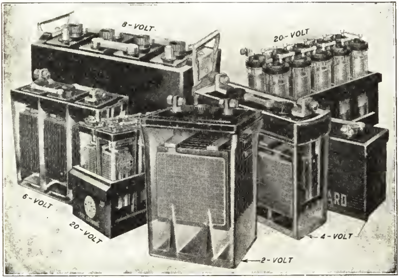


Fig. 18. A Few Stationary Storage Batteries of Different Voltage Ratings
Courtesy of Willard Storage Battery Company, Cleveland, Ohio

to such an extent that it overflows the space provided for it, it will short the plates of the cell and ruin the battery.

Size and Number of Plates. As in the primary cell, the size of the plate has nothing at all to do with the voltage of the cell. The lead storage cell has an open-circuit voltage of 2.2. Its working voltage is 2 volts per cell. The size of the plate, however, does determine the amount of current that a cell will deliver. The larger the plate surface exposed to chemical action, the more current the cell will deliver. To avoid using plates of excessive size, they are assembled in groups, and the total area of the exposed surface of these groups determines the current output of the cell. The more plates there are in a battery, the greater is the current output.

Stationary Batteries. Manufacturers of storage batteries usually designate the batteries used in farm lighting plants, and similar installations, as stationary batteries. Batteries of this type have certain things in their favor. They do not have to be built down to space limitations, as do those used in automobiles. Once they are installed, there is little danger of their cases becoming damaged, since they are not subjected to jolts and jars, and they often remain

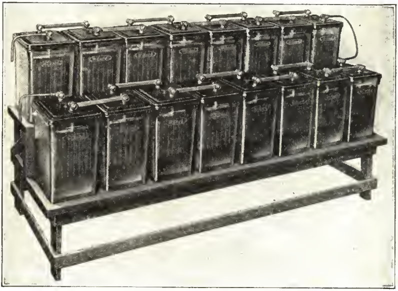


Fig. 19. A Group of 16 Cells, 32-Volt, Mounted on a Rack
Courtesy of Willard Storage Battery Company, Cleveland, Ohio

in one location for years. Sometimes the cells are not even sealed. Fig. 18 shows several of the many types of stationary batteries now in use. Many installations of stationary batteries consist of banks of cells stored on racks, as shown in Fig. 19.

A Modern Planté Battery. An interesting battery on the present-day market is the one which the Gould Storage Battery Corporation call their Planté battery. The interesting feature of this battery is its use of a Planté-type positive plate, and a Faure-type negative plate. Through an intricate process, the Gould Corporation has been able to produce a pure lead one-piece positive plate of the Planté type that has an exceptionally long life. See Fig. 20. This process is

known as the spun-plate process, and it results in an extensive area of exposed plate. In connection with this Planté-type positive plate, there is used a regular Faure negative plate, similar to the plate shown in Fig. 14. Since much of the deterioration in a battery occurs around the positive plate, the longer life of the Planté-type plate will naturally prolong the life of the battery. Fig. 21 shows this cell

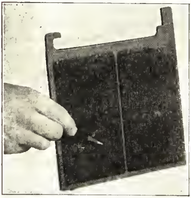


Fig. 20. A Planté Plate, Showing the Ridges and Grooves Produced in the Plate
Courtesy of Gould Storage Battery Corporation, Depew, N.Y.

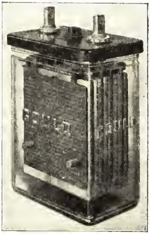


Fig. 21. An Assembled Planté Type Storage Cell
Courtesy of Gould Storage Battery Corporation, Depew, N.Y.

assembled in a glass case. The positive plate, however, is concealed by the separator and the negative plate.

Uses of Storage Batteries. The automobile has brought the storage battery into extensive use, so that some idea of its construction and function is common to everyone. These batteries are now serviced in every community, and their structure may be studied by anyone who is interested in scientific things.

Because there are many automobile-type storage batteries on the market, people have come to think that all storage batteries are like these. On the contrary, the automobile storage battery is a specialized form of the storage battery, built in conformity with certain exacting requirements in a manner that has called for the sacrifice of certain desirable features, including length of life. The life of such a battery is far below that of the stationary battery. You

will understand this when you consider that the chief function of the automobile battery is to furnish power to the automobile engine starting motor. This is a heavy load. No battery would be able to furnish this extremely large current if the demand were for more than a few seconds at a time. Even to supply it for short periods, changes had to be made in the construction of the plates. The plates used in automobile batteries are extremely thin, for it is only by use of very thin plates that the batteries withstand this severe current strain. Thin plates, however, make for a short battery life. Stationary batteries, having thick plates, last much longer.

Stationary batteries are found in the small, isolated lighting plants on the farm or at the summer resort. They also are used in many of the larger lighting and power plants, for stand-by emergency service. They are important factors in the great telephone systems, where they have furnished dependable service over long periods. They are a part of most alarm and signal systems. They are used in sound projection, and in sound recording. They are used extensively by railways for lighting and air conditioning. All in all, the storage battery plays a most important part in present-day industry, where it is recognized as a reliable source of power.

THE EDISON STORAGE BATTERY

The Edison Storage Battery is the nickel-iron-alkaline type. It is one of the electrical devices developed by Thomas A. Edison. Unlike the lead-acid storage battery, of which there are many types, put out by many manufacturers, there is but one nickel-iron-alkaline storage battery on the American market, the one made by the Edison Company. It is built in many sizes and for many uses by this company.

Edison was not satisfied with the lead-acid storage batteries, which, as a matter of fact, had many objectionable features at that time. They were messy, when leaky cases allowed electrolyte to ooze out and corrode or destroy with its caustic action the materials near it. There was the hazard of poisonous or explosive fumes which these cells presented, as well as the injury incurred by plate sulphation if the lead-acid cells were not kept in almost constant use. Also, they suffered some damage from sulphation even in normal use, and in order to break this sulphation down, extreme care was used in adjust-

ing their charging currents; otherwise the batteries would have been ruined. Their heavy plates were enclosed and supported by cases of rubber composition which did not resist shocks of even moderate intensity, so that containers were often fractured.

Edison, then, set out to design a battery that would do away with these objectionable features. He worked at it a long time, and as the work progressed, reports of his progress were published. Industry everywhere awaited the results with interest.

The Edison battery was put on the market in 1908, having overcome many of the difficulties involved in the use of the lead-acid cell.

The new battery had an alkaline electrolyte. There was no acid to spill, no hazard from corrosive fumes. The battery could be put in service, then taken out of service and kept out for long periods, without injury. Its recharging could be handled by amateurs, as, without sulphation, the rate of the charging current was of little consequence. It was sturdily built so that even repeated major shocks could not damage it. It did not require repairs, and its normal life was many times that of the old battery. In fact, its life was stated to be from eight to sixteen years.

However, there were some important features which the public demanded that Edison was not able to build into his new battery. Thus, it came about that the much-heralded new battery did not sweep the lead-acid battery from the market. It is true that there are places where it has a distinct advantage over the lead-acid type, but it has not replaced them extensively.

For one thing, potential in a battery is a matter determined by the materials of which the electrodes are composed, and by the type of electrolyte used. To use alkaline as an electrolyte, narrowed the choice of plate materials to those which resulted in establishment of a potential which produced an electromotive force (e.m.f.) of 1.2 volts per cell. This is about one-half of the voltage of a lead-acid type cell, which meant that two cells of the new battery had to be installed for every cell of the lead-acid type displaced. The new battery then would be approximately twice the size of the lead-acid type. Also, the cost of the alkaline battery is more per cell than that of the lead-acid battery.

Also, there is a lowering of efficiency, in the alkaline battery,

with lower temperatures, especially below 40 to 50 degrees Fahrenheit. You can go out to your garage on a sub-zero morning and start your car, with its lead-acid type of battery, though even in this type there is, admittedly, some loss of efficiency at these low temperatures. However, you do not find any nickel-iron-alkaline *automobile* batteries on the market.

Installations in which the nickel-iron-alkaline batteries have proved superior are where the batteries have long periods of disuse; where acid fumes would be particularly destructive; and where batteries are subjected to jars and shocks. It is reported, also, that high room temperatures will not damage them, and, consequently, there have been set up many installations of these batteries in the tropics. It is recommended that they be operated at temperatures under 115 degrees Fahrenheit where possible.

These batteries are found in school laboratories, since they are not damaged by disuse during long vacations. They are employed in stand-by service, such as in light and power plants, for emergency power to drive ship steering gear, and in similar places where they are likely to have long periods without use. You will find them on many of the streamlined trains, and on private railway cars in which they have intermittent use. They often are installed in mine locomotives or industrial trucks, where jars and jolts are frequent and severe.

Construction of the Edison Storage Battery. The positive plates are made up of many perforated steel tubes, having approximately

Fig. 22. Edison Positive Tube Containing Nickel Hydrate

530 perforations per square inch of surface. This type of tube is shown in Fig. 22. Each tube is filled with approximately 630 alternate layers of active material, namely nickel hydrate and nickel flake, tamped in with a pressure of 2000 pounds to the square inch. Each tube is reinforced with eight steel rings, and then all are welded into a steel grid to form the positive plate as shown in Fig. 23.

The negative plates are constructed of many individual steel containers or pockets, having 1900 perforations to each square inch

Fig. 23. An Assembly of Tubes in a Positive Plate of an Edison Cell

Fig. 24. An Edison Negative Element or Pocket

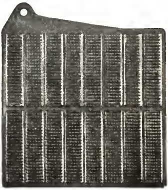


Fig. 25. An Assembly of Edison Pockets Forming the Negative Plate

of surface. These pockets are shown in Fig. 24. They are loaded with active material, which consists of finely powdered black oxide of iron with a small amount of mercury mixed through it to improve its conductivity and to aid in the chemical action. These containers are assembled into steel grids to form the negative plates, shown in Fig. 25.

The positive plates are grouped together and assembled on a grid-terminal block to complete the positive group assembly, and the negative plates are assembled and attached to another grid-terminal block to form the negative group assembly. These two groups are meshed together, but the plates are separated from each other by rubber grid insulators. This assembly is shown in Fig. 26.

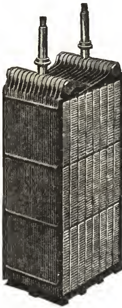


Fig. 26. An Assembly of Plates of an Edison Cell

The assembled elements are inserted into a nickel-steel container from which they are insulated by rubber pin-insulators. Since the battery does not need repair, the container cover is welded into place on the container. The sealing is complete, the only outlet being the filler cap. The upper portion of one of these cells is shown in Fig. 27.

No provision is made in the container for a sediment space, as will be found in the bottom of a lead-acid type cell, for the chemical action in this battery is such that no sediment will be deposited.

The electrolyte is a solution of caustic potash, held at a specific gravity of 1.200. The solution is such that it acts as a steel preserva-

tive, rather than producing any deterioration of the steel battery parts. This means that there will be no corrosive attacks to eat away the container and cause leakage.

Fig. 27. A Pressed Steel Container of an Edison Cell Showing Terminals and Cap with Safety Valve

Moreover, the entire assembly is so rugged that it will resist mechanical shocks that would ruin cells of the lead-acid type. It will, in fact, survive most major shocks in good condition.

These nickel-iron-alkaline batteries may stand idle over long periods of time without injury, by the simple process of discharging the cells and shorting the battery.

Other superiorities claimed for this battery are the prevention of injury from overcharging, by this sturdy construction, and the fact that the alkaline electrolyte eliminates the possibility of freezing, as well as eliminating corrosive fumes and connector corrosion.

Fig. 28 shows a cutaway view of an Edison cell, and in Fig. 29 you will see four of these cells mounted portably for convenience in handling and for use, such as in school laboratories.

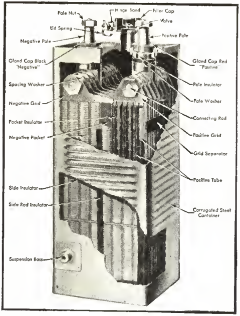


Fig. 28. Cutaway View Showing Plate Assembly of an Edison Cell

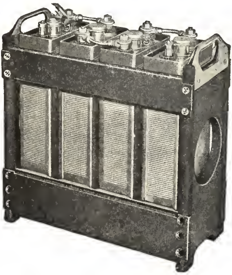


Fig. 29. Four Edison Cells Mounted in a Rack
Courtesy of Thomas A. Edison. Inc., Orange, N. J.

REVIEW QUESTIONS

1. What is the difference between an *electrical cell* and a *battery?*

2. What are the necessary ingredients of a fundamental electrical cell?

3. Describe the difference between the *primary* cell and the *secondary* or storage cell.

4. What is a *closed-circuit* cell? An *open-circuit* cell?

5. What is *polarization* and what is its effect? How may it be overcome?

6. How is a dry cell constructed? What is used for the electrodes, electrolyte, and depolarizer?

7. In the lead-acid storage cell what forms the active material of the *positive* plate? Of the *negative* plate? What is the *electrolyte?*

8. What relationship exists between the specific gravity of the electrolyte in a storage battery and its state of charge?

9. What is *excessive sulphation* and what causes it? What is the result of excessive sulphation?

10. What determines the current output of a lead storage battery?

11. In the Edison storage battery what materials are used in the positive and negative plates, electrolyte and container?

12. What is the *open-circuit potential* of the lead-acid storage cell? Of the Edison cell?

APPLICATIONS TO INDUSTRY

1. If a mechanic testing your automobile storage battery said it read *eleven-fifty*, what should you do?

2. Why is it a good idea to remove flashlight cells from your flashlight before laying it aside for a long period of time?

3. What are the chief differences between lead-acid storage batteries that are designed for automotive use and those for stationary use?

4. If the sludge at the bottom of a lead-acid storage battery gets too deep, what can happen?

5. When lead-acid storage batteries are to be stored for a period of time, should they be stored in a discharged or fully charged condition?

6. How many cells are there in a 6-volt automobile storage battery?

7. From your experience name some of the uses to which storage batteries are put.

8. What instrument is used for measuring the state of charge of a battery?

9. What would a completely *charged* battery read? What would a completely *discharged* battery read?

10. How is a portable radio battery voltage of 22½ volts obtained by the use of unit dry cells?

FOUR 35,555-KVA HYDROELECTRIC GENERATORS, WHICH DEVELOP POWER AT 13,800 VOLTS, MAKE UP THE INSTALLATION AT FORT LOUDON DAM

Courtesy of Allis-Chalmers Mfg. Co., Milwaukee, Wis.

OHM'S LAW

ELECTRICAL CIRCUITS

Conductors and Insulators. You have been shown that, as far as electricity is concerned, all materials can be divided into two classes. These two classes are known as **conductors** and **insulators.** And, strange as it may seem, while these two classes are supposed to be opposite to, and differ greatly from each other, there is no definite line which can be drawn dividing one class from the other. This is because that each material, occurring in either class, contains some of the properties of those materials listed under the other class headings. For instance, our very best conductors offer some resistance to electrical currents—we have no perfect conductors—therefore, they contain some of the properties of insulators. Again, we have no insulators but that will, under certain conditions, pass or "leak" current. They then possess some of the properties of conductors. If one were to make a list of materials, beginning with the better conductors and adding to this list those materials of poorer conductivity (ability to conduct electricity) in their order, a test of this ability would soon show that the materials being listed were so poor in conductivity that they could well be classed as insulators.

Selection of Electrical Materials. Materials are selected for certain jobs if they fall within the limits necessary for the conductance or the insulation of the currents required upon that job. Almost any insulator is of use in some phase of electrical work. Generally, the higher the voltage employed in a circuit, the more necessary the use of better insulators. Again, the smaller the current used through the circuit, the poorer the conductor may be. A common illustration of the latter, is the general use of iron wire for country telephone circuits. These circuits have very small currents through them, and so iron, a poorer conductor than copper, may be used for line wires. As iron is much cheaper than copper, the additional expense of forcing the small telephone current through this material of higher resistance will rarely equal the difference in the cost of the materials.

Adjustment of Pressures When Insulation Is Poor. The poorer and cheaper insulation materials are used on circuits of low pressures. It sometimes happens that because of construction difficulties and costs, it is almost impossible to provide a sufficient insulation for circuits of a desired pressure, and so the pressure of that circuit must be cut down to fit the case. This is illustrated in the **block** signal system in use in railway work. Here, a train passing along a certain section or **block** of track causes signals to be flashed from

Fig. 1. Semaphore Block Signals
Courtesy of Union Switch and Signal Company

semaphores, as shown in Fig. 1, located ahead of and behind the train. The completion of the electrical connection for the operation of these semaphores is made from one steel rail of the track through the wheels and axles of the train to the other track rail. In the building of the track, care was taken to have no metal connection between these rails, and that the different blocks of the track were insulated from each other. Each line of rails is insulated from the other line by the regular wooden **crossties** of the track. Wooden crossties are made use of, because wood seems to be the only material that will stand up under the severe strain imposed upon the rails and ties by the passing trains. Now wood is a very good in-

sulator when dry, but no provision can be made to keep wooden crossties dry as they are in the open and subjected to rains, floods, and snows, which turns them from good insulators into fair conductors. It was found, however, that if the voltage of the circuit were to be reduced sufficiently, there would still be enough of the insulation properties remaining in the wet tie to allow the circuit to function, although very weakly; and this feeble action, through the use of relays, is made to perform the work. This is an expensive process and one hard to maintain, but it is necessary in this case in order to surmount the difficulties of poor insulation.

Line Wires. The selection of materials for use as line wires for the conveying of electric currents is made after a consideration of the possibilities of the purchase of the material in quantities; its first cost, and relative cost of installation; and its degree of conductivity, that is, if it has low enough resistance to transmit the current.

Fig. 2. Glass Insulator Used on Telephone and Telegraph Lines

Iron wire is the cheapest but it has so much resistance compared to copper, that it cannot be used for sending heavy currents. Silver is probably the best of conductors, but of course its cost is so great that its use is prohibitive. Copper seems to be the material more nearly meeting all of the requirements.

Insulators. While there are many materials which are available for insulators, one of the factors entering into the selection of a material apart from its insulating qualities is the ease in which it can be put into a convenient shape for use. For line work, glass and porcelain seem to more nearly meet the requirements and are in extensive use. A glass insulator commonly used on telephone and telegraph lines is shown in Fig. 2. Porcelain requires glazing

where exposed to the weather, for unglazed porcelain presents a porous surface to the weather for the collection of moisture, and this makes it something of a conductor, destroying its insulation qualities. The rules for wiring which are laid down by The National Board of Fire Underwriters, and known as "The National Electrical Code," specify "that insulators must be non-absorptive," which precludes the use of porous material. The only exception to this is found in unglazed porcelain tubes, which are never to be used where they are exposed to moisture.

Another material which lends itself readily, in a peculiar way, to this forming process and which has done much to further the use

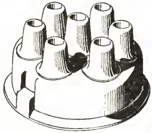


Fig. 3. Distributor Cap Used on an Automobile

of high voltages in automotive ignition work is bakelite. This material comes to the manufacturer in its powder form, which is similar to flour. It is moulded in special presses under pressure into intricate shapes. Then it is subjected to a specified baking process which sets it permanently in these shapes, and it is thereafter almost indestructible. Formerly, moulded rubber was used for this work. Now rubber is a good insulator, but it can be remelted by the heat from the automotive engine, while bakelite is never again affected by heat. A bakelite distributor cap from an automotive ignition system is shown in Fig. 3.

Electrical wires used in the wiring of houses, offices, factories, etc., for light and power, have an insulation of moulded rubber, which is in turn protected from mechanical injury by a braid of woven cotton threads, Fig. 4. This insulation is to prevent the current from flowing from one wire of a circuit to the other wire of the circuit.

Wires used in the windings of the coils in electromagnets, electric motors, and generators, have an insulation made by the wrapping of very fine silk or cotton threads, Fig. 5, around the wires, or by the dipping of the wires in an electrical insulating varnish, called enamel.

PRODUCTION OF HEAT

Heat Losses. When the electrical pressure is sufficient to force a current through a resistance, heat is produced. As all conductors possess resistance, it stands to reason that there is heat produced in all circuits. In the ordinary circuit this amount of heat is small and can easily be lost by radiation. The production of heat, however, is a charge in the form of energy, which is always an expensive procedure; and as this heat is seldom put to use, that part of the electrical energy used in its production is a direct loss from the whole

Fig. 4. Rubber-Covered Wire

Fig. 5. Double-Silk or Double-Cotton-Covered Magnet Wire

amount sent through the line. This then accounts for what is known as **transmission losses.**

This heating effect of a current must always be taken into consideration, and care must be used to provide sufficient radiation, especially if the conductors are to be wound into closely packed coils; otherwise the delicate wire coverings may be charred and burned, resulting in a mass of melted copper rather than a coil.

Heating Devices. There are times when this heating effect of the current is put into good use, and then the heat is not a loss but a distinct advantage. Many different types of apparatus have been designed, which make use of this **heating effect** of the electric current. Some examples of these are the electric toaster, the electric hot plate or stove, Fig. 6, the electric flat iron, Fig. 7, the electric heater, Fig. 8, etc. Apparatus of this type makes use of a special wire which is usually an alloy or composition of several metals of which nickel and chromium are the principals, and this is combined into a special form and known as a heating element. This alloy is

of high resistance with also the property of withstanding high temperatures. This means that the wire does not melt at red and white heats, at which several of the above named devices must be operated.

Our common electric lamp globe is also an example of apparatus using the **heating effect** in its operation. The light is not obtained directly from the electricity used in the lamp, but from its filament which is maintained by this current at incandescence, which is a white

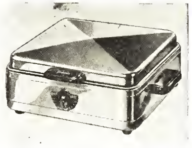


Fig. 6. Waffle Iron

Fig. 7. Electric Flatiron

Courtesy of Sunbeam Corporation, Chicago, Ill.

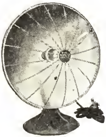


Fig. 8. Electric Heater
Courtesy of Rock Island Manufacturing Company

heat. The fuse, Fig. 9, used to protect our circuits from overloads and consequent injury, is another example of the use of this **heating effect.** The fuse is designed to carry safely a certain current, but to heat up sufficiently to melt and open the circuit, should more current be forced through it.

Uses of Resistance. Resistance plays a very important part in electrical work. Resistance in materials other than metals seems to form our best insulators, while resistance in the proper metals

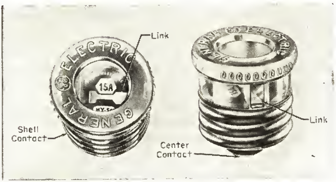


Fig. 9. Modern Plug Fuses
Courtesy of General Electric Company, Schenectady, N.Y.

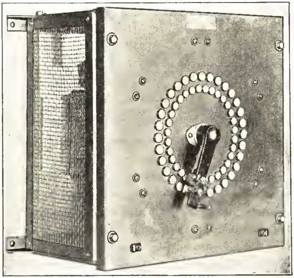


Fig. 10. Adjustable Field Rheostat
Courtesy of Cutler-Hammer, Inc.

furnishes us with heat and light. Resistance in conductors furnishes us with a method of controlling pressure, and consequently current, in our electrical circuits. The introduction of resistance in an existing circuit divides up the pressure across that circuit between the resistance introduced and the other parts of the circuit. This will then lower the voltage across the parts of the original circuit and result in a lessened current flowing through the entire circuit. If the resistance introduced be of a variable type, then the voltage and current of the circuit can be changed at will. The resistance is then known as a rheostat. A commercial rheostat is shown in Fig. 10.

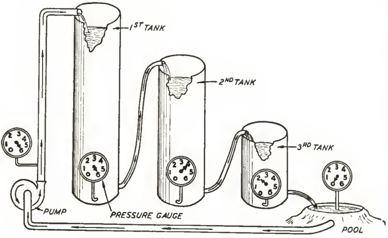


Fig. 11. Flow of Water through a Pipe System

The pressure of a circuit is divided up in the circuit according to the resistance of the individual parts of the circuit. That is, as the current is forced through each of the various devices, conductors, and wires, which make up the circuit, some of the pressure is consumed or lost. This can be illustrated by the water analogy as shown in Fig. 11. Here are three tanks of similar construction, all equipped with pressure gauges located near the bottom of the tanks. They are, however, of three heights, the middle one being two-thirds and the smallest one being one-third the height of the largest one. Water enters the largest one through a pipe from the pump, Fig. 11, at its top, and a length of hose is led from the bottom of the first

tank to the top of the second tank and from the bottom of the second tank to the top of the third tank. From the last tank, the water flows off to a pool which is level with the bottom of all the tanks.

The pressure gauge located at the bottom of the first tank shows a pressure of six pounds. As the water flows on into the next tank some of the pressure is lost through the doing of the work necessary to convey the water to the second level and as this level is just two-thirds that of the first tank, the pressure shown by the gauge on the bottom of the second tank will be just two-thirds of the

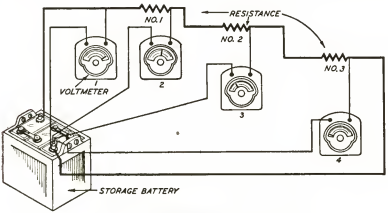


Fig. 12. Flow of Electric Current through a Circuit

pressure as shown by the gauge on the first tank. Two-thirds of six is four, the pressure of the second tank. This amount is shown on the gauge. The water flows on into the third tank; it loses pressure as it flows, and its gauge indicates that there is a pressure in it of just two pounds. This is as expected for it is of a value of one-third that of the largest tank. A gauge placed at the pool would show a zero reading, indicating that there was no pressure left in the system, that it had all been consumed in the work necessary to move the water through its course. The pump returns the water from the pool to the first tank.

Similar to this action of the water in Fig. 11, is the action of the electrical circuit of Fig. 12. Here a six-volt storage battery supplies the entire pressure of the circuit. The current flows from

the storage battery through the three resistances which are numbered *1*, *2*, and *3*. The voltmeter which is connected across the storage battery is the electrical pressure gauge, and it shows a pressure of six volts. Another voltmeter is connected at a point just after the first resistance. This will show the pressure of the current after the pressure has been reduced somewhat by the work of forcing the current through the first resistance. Just as the pressure of the water system of Fig. 11 had lost two pounds after the effort of filling the second tank, so the electrical pressure in Fig. 12 is reduced two volts by the effort of forcing the current through the first resistance, and so the voltmeter *2*, placed after this resistance, will show a reading of four volts. In a like manner the voltage of the circuit will be reduced another two volts by the effort of forcing the current through resistance No. *2*, and this will be shown by a reading of two volts on voltmeter *3*. And voltmeter *4*, placed after resistance No. *3*, will show a pressure of zero, indicating another two-volt drop. The devices with the highest resistance will cause the largest loss of pressure and the ones containing the smallest resistance will cause the smallest loss of pressure.

EXPLANATION OF OHM'S LAW

Electrical Measurements. This brings us down to the point in the study of our electrical circuits where, if we wish to know definitely of these circuits, it is necessary to apply measurements to their separate parts. Perhaps you had not thought of the important part that measurements of any kind play in our economic advancement. Without the establishment of units and the use of these units in measurements and calculations, it would be impossible to build even the simple devices so necessary to our comfort and pleasure. This all applies to articles of furniture, to clothing, to the laying out and to building of roads as well. If these measurements are necessary in things so visible as these, it is equally as necessary with the more or less indefinable subject of electricity.

Three Factors of the Circuit. You have seen where the three important factors of the electric circuit are **pressure, current,** and **resistance.** These, however, are general terms and must be broken up into units for accurate handling in measurements. Just as the unit of distance in lineal measurement is the foot, and the unit of

physical pressure is the pound, so the unit of electrical pressure is the volt. You, perhaps, could not define these units the foot and the pound (other than by breaking them up into smaller units), nor do you have to know the history of their origin in order to use them in accurate measurements. Nor will it be necessary, as far as the ordinary use in commercial work is concerned, for you to go into the history of this unit of electrical pressure and these other units of current and resistance. It is sufficient, for the present at least, for you to know that:

The **volt** is the **unit** of electrical **pressure.**

The **ampere** is the **unit** of electrical **current.**

The **ohm** is the **unit** of electrical **resistance.**

That these three factors of the circuit—the volt, the ampere, and the ohm—were the key factors to the study of electrical circuits and their actions, was the conclusion of George Simon Ohm, a German scientist, as he pondered over the question in 1827, and from these conclusions he formulated the all-important **Ohm's Law** which stands today as the basic formula underlying all electrical theory and measurement. The unit of resistance was given his name. This famous Ohm's Law is the simple statement that:

The current in an electric circuit is equal to the pressure divided by the resistance.

This law can also be written in formula form:

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}}$$

NOTE: The above formula is read **current** equals **pressure** divided by **resistance**. In a formula when a word, letter, or number is placed above a line and over another word, letter, or number, the line has the same meaning as the sign $\div$, which is read *divided by.*

This is far too unwieldy a form for quick use, and so abbreviations, symbols, or letters are used to represent these words:

Pressure = Volt = E
Current = Ampere = I
Resistance = Ohm = R

In explanation: the **E** is the first letter of the term **electromotive force,** which is used in the study of pressure when the units

are unknown; the **I** is the first letter of the term **intensity of current,** which is used rather than letter **C,** for the latter is a symbol which has other uses; and the **R** is the first letter of the word **resistance.** Thus, the formula

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}} \text{ can now be written } I = \frac{E}{R}$$

This formula, of course, is of use only to find the current when you know the pressure and resistance. The formula can be rearranged so that the letter which stands for what you want to find is on the left side of the equality sign. As there are only three members of this formula, there are just three possible forms of arrangement. They are:

$$I = \frac{E}{R} \quad E = IR \quad R = \frac{E}{I}$$

Learning Ohm's Law. As there are just these three forms of this formula, it is best to learn them as written above. Do not read them hurriedly and pass them by, but learn them thoroughly, for they are absolutely necessary to your understanding of the subject. Perhaps a study of them will help fix their relations in your mind.

Since Ohm's law is one of the most commonly used fundamentals of electricity, it is essential that it should be memorized. A very ingenious way of representing and of memorizing Ohm's law is embodied in Figs. 13 to 16. If any one part be removed or covered, the relative position of the other two gives the value of the one covered in terms of the other two.

Fig. 13. Ohm's Law

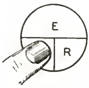


Fig. 14. Current

Thus if we cover I, Fig. 13, $E \div R$ is left, Fig. 14. Therefore the value of I in terms of E and R is E divided by R. If R is covered, $E \div I$ remains, Fig. 15, giving the value of R in terms of E and I.

which is E divided by I. In the same way, if we cover E, we have its value remaining in terms of I and R, namely, I times R, Fig. 16.

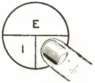


Fig. 15. Resistance

Fig. 16. Voltage

Example 1

A voltage of 6 volts is used to force a current through a resistance of 3 ohms. What is the current?

Solution

The voltage (E) is 6 volts and the resistance (R) is 3 ohms, we wish to find the current (I). Using the first statement of Ohm's law we find that

$$I=\frac{E}{R}=\frac{6}{3}=2 \text{ amperes}$$

Example 2

What voltage is required to force a current of 2 amperes through a resistance of 10 ohms?

Solution

The current (I) is 2 amperes and the resistance (R) is 10 ohms. We want to find the voltage (E).

$$E=I\times R=2 \text{ amperes}\times 10 \text{ ohms}=20 \text{ volts}$$

Example 3

A voltage of 20 volts is required to force a current of 5 amperes through a coil. What is the resistance of the coil?

Solution

Voltage (E) = 20 volts. Current (I) = 5 amperes

$$R=\frac{E}{I}=\frac{20 \text{ volts}}{5 \text{ amperes}}=4 \text{ ohms}$$

Example 4

The voltage between the ends of a piece of wire is 15 volts and its resistance is 3 ohms. What current will flow through it?

Solution

Covering the symbol I in the diagram, Fig. 13, there remains $E \div R$. Substituting the values of voltage and resistance given, we have $15 \div 3 = 5$ amperes.

Example 5

A current of 10 amperes is forced through a conductor by a pressure or voltage of 30 volts. What is the resistance of the conductor?

Solution

Covering R in the diagram, Fig. 15, we have left $E \div I$. Substituting for E and I their values from the conditions as stated, we have $30 \div 10 = 3$ ohms.

Example 6

A current of 10 amperes flows through a resistance of 2 ohms. What is the voltage that is forcing the current through the resistance?

Solution

Covering E, Fig. 16, we have left I times R. Substituting their values as before, we have $10 \times 2 = 20$ volts.

Applications of Ohm's Law

Ohm's law may be applied to a circuit as a whole or it may be applied to any part of the circuit—a circuit being the path through which a current flows from its source through a conductor back to its source. A great amount of caution and practice is required to apply this law correctly in all cases. Accordingly, there is no part of electrical work where so many mistakes are made as in the application of this simple law. Once the principle is firmly grasped, the student is prepared to handle correctly a wide range of electrical problems.

Many of the difficulties will be cleared up if the student will keep in mind the following two statements and will use them intelligently.

When applying the law to the *entire* circuit, state the law as follows:

(1) The current in the entire circuit equals the voltage across the entire circuit divided by the resistance of the entire circuit.

Notice that the term *entire* applies to current, voltage, and resistance. Not to one of them, but to *all* the factors of the equation.

When applying the law to a part of the circuit, state the law as follows:

(2) The current in a certain part of a circuit equals the voltage across that same part divided by the resistance of that same part.

Notice here again that the values for current, voltage, and resistance are taken from the *same part* of the circuit. By far the greatest number of mistakes in applying Ohm's law come from dividing the voltage across one part of the circuit by the resistance of some other part of the circuit and expecting to get the current in some part of the circuit.

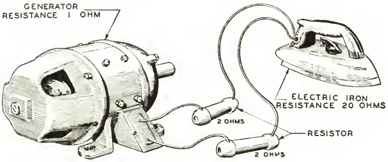


Fig. 17

Example 7

Fig. 17 is a drawing of a typical direct-current circuit. The generator has a resistance of 1 ohm and generates 150 volts at no load. Each line wire has a resistance of 2 ohms. The iron which represents the load has a resistance of 20 ohms. What is the current in the circuit?

Solution

The resistance of the entire circuit is the resistance of the generator plus the resistance of the lines plus the resistance of the load, or

$$R=1+2+2+20=25 \text{ ohms}$$

The total voltage produced is 150 volts, therefore the current is

$$I=\frac{E}{R}=\frac{150}{25}=6 \text{ amperes}$$

IR Drop

The electromotive force of a generator, such as a dynamo or a battery, is the potential difference maintained between its terminals when no current is being taken from it. When current is taken from the generator, the terminal voltage—that is, the voltage applied to the line—is less than the open circuit voltage by an amount equal to the resistance drop or IR drop in the generator. The potential difference existing between two points in a circuit is called drop in potential, potential drop, fall of potential, voltage, and the like.

By Ohm's law the voltage drop in any *part* of a circuit is equal to the current in that part multiplied by the resistance of that part of the circuit.

$$E=I\times R \text{ volts}$$

in which E is the voltage, I the current, and R the resistance of *that part* of the circuit.

Thus the fall of potential in that portion of a circuit whose resistance is R is often called the "*IR drop*", as the IR drop applies to any *part* of the circuit it will also by proper use apply to the entire circuit.

Example 8

What is the IR drop across the electric iron shown in Fig. 17, when 6 amperes are flowing through it?

Solution

$$IR \text{ drop}=6\times 20=120 \text{ volts}$$

Example 9

In Fig. 17 what is the voltage drop in the line when a current of 6 amperes flows through the circuit?

Solution

The total IR drop in the line will be twice that in one of the wires. The total line drop is

$$IR \text{ drop} = (6 \times 2) \times 2 = 24 \text{ volts}$$

Example 10

What is the IR drop in the generator when it is delivering a current of 6 amperes?

Solution

$$IR \text{ drop} = 6 \times 1 = 6 \text{ volts}$$

Example 11

What must be the open circuit voltage of the generator in order that it deliver a current of 6 amperes to this circuit?

Solution

Electromotive force $= 120 + 24 + 6 = 150$ volts
Or, total resistance $= 1 + 2 + 2 + 20 = 25$ ohms
Total IR drop in circuit $= 6 \times 25 = 150$ volts

Suppose that the circuit to the electric iron is opened by removing one of the wires fastened to the electric iron. Then when a voltmeter is connected to the two wires coming from the generator shown in Fig. 17, it will read 150 volts. The voltmeter will also read 150 volts when it is connected to the wire removed from the iron and the wire fastened to the iron. The reason for this is because there is not any current flowing through the circuit, and the voltage between the two wires of the circuit is the same at all points.

Now reconnect the wire back to the electric iron, and the voltmeter will read 120 volts between the two wires connected to the electric iron. (See example 8.) It will read 144 volts (150 less 6 volts drop in generator) at the terminals of the generator. The difference between the voltage at the electric iron and that at the generator is 24 volts (see example 9) which are used up in forcing the current through the line which has a resistance of 4 ohms. Thus the IR drop is the voltage used in forcing a current through the circuit to the point where it is made to do useful work.

Emphasizing the Importance of Pressure. You have seen how the statement in the formula **E = IR** shows the volts to be the largest

and perhaps the most important member of the formula. You will also remember that the scientist, Ohm, devised this formula to represent the actual relations of the circuit over a long period of tests; and he was so accurate in his assumptions that today, after more than one hundred years, the formula is in universal use without a thought as to its change. As this formula represents the actual relations of the circuit, then it is true that the pressure is the essential factor of the circuit. This is as certainly true in the water or hydraulic systems, to which for the sake of study, the electrical circuits are continually being compared.

In the water system the pipes may be full of water, but none will flow at the faucet unless there is pressure in the water mains. Just so in the electric circuit, there is no current flowing in the circuit unless there is electrical pressure in that circuit.

An electrical generator is simply a device for keeping up pressure in an electrical system. When the generator stops, the pressure is cut off and the current ceases to flow.

From these statements we can see the direct effect upon the current of a circuit is caused by the changing of the circuit's resistance. Any change in the resistance will increase or decrease the total resistance of the circuit which holds back the pressure, and a corresponding change results in the current flowing through the circuit. From this is also gained an idea of the interrelation between pressure and current, and how the volume of the current is directly dependent upon the pressure of the circuit.

Pressure is a factor supplied from an outside source, as the storage battery in Fig. 12; the amount of current is a result of a balance between pressure and resistance; while resistance is a physical part of the circuit and its change is only effected by a physical change in the apparatus.

It is true that no current is lost as it passes through the circuit. If any current flows at all, it flows from the source of power through the entire circuit and back again to the power source. Pressure is the only one of these three factors which suffers a loss, and its value is reduced to zero as the point in its travels through the circuit is reached where it again enters the source of power.

Current can be controlled through a voltage change and this is usually done through the adjusting of a resistance.

REVIEW QUESTIONS

1. Why can't all substances be classified either as *insulators* or *conductors?*

2. What are the requirements of an insulator in a circuit in relation to the amount of voltage applied? What are the requirements of a conductor in relation to the amount of current it carries?

3. When is *wood* a satisfactory insulator? When not?

4. When selecting wire for a line, what factors must you consider?

5. What is *transmission loss* and what causes it?

6. Give some examples in which the heating effect of an electric current is used to advantage.

7. If a resistance is connected in series with an electrical circuit, what effect does it have upon the voltage across the circuit? Upon the current flowing through the circuit?

8. What are the three important factors or units of an electrical circuit? What does each stand for?

9. State Ohm's law. Indicate it in formula form for each of the three factors.

10. What is meant by *IR Drop?*

APPLICATIONS TO INDUSTRY

1. In a country telephone circuit is it more practical to use iron lines or copper lines? Why?

2. Why is glass instead of unglazed porcelain used as insulators on telephone and telegraph lines?

3. Why is *bakelite* often used as the distributor cap in the ignition system of an automobile?

4. In what way is the fuse an example of *heating effect?*

5. If a generator is connected to a load, will the voltage across the load be higher, lower or the same as the generator terminal voltage? Why?

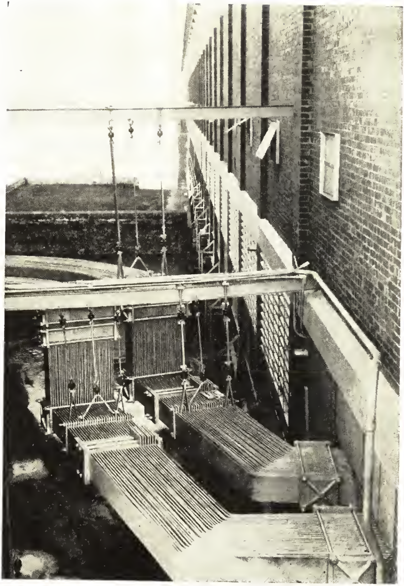
6. If you were to connect an electric heater having a resistance of 4 ohms to a 32-volt circuit, how much current would the heater take?

7. A 15-candlepower, 12-volt automobile light bulb has a resistance of 12 ohms. How much current would pass through the bulb if it were connected across a 12-volt battery? A 6-volt battery?

8. If a standard 110-volt light bulb took a current of 1 ampere from the line, what would be its resistance?

9. If you had a number of 40-watt 110-volt bulbs on hand, how could you connect them to a 220-volt line without "blowing" the light bulbs? Illustrate with a diagram.

10. If a 110-volt light bulb were connected to a 32-volt circuit, would the bulb burn brightly or dimly? Why?



HEAVY CURRENTS REQUIRE CONDUCTORS OF LARGE CROSS-SECTIONAL AREA
These aluminum bus bars are used to conduct 60,000 amperes at Niagara Falls, New York.
Courtesy of Aluminum Company of America, Pittsburgh, Pa.

SERIES AND PARALLEL CIRCUITS

So far we have confined our discussion to the various modifications of the simple circuit and have introduced you with the task of tracing a circuit. The discussion which is to follow will take up the various modifications of the simple current and introduce you to some of the elementary engineering problems of the series and parallel circuits.

Current=Producing and Current=Consuming Devices. Generators and batteries are classified as current-producing devices, while almost all of the other electrical devices are known to the electrical trade as current-consuming devices. The name current-consuming is, in a way, misleading, for you have just been told that no current is lost or consumed in its journey through a circuit. I presume that the term originated in the fact that all of the devices required current to make them function. They do not, however, actually consume any of the current of the circuit.

The subjects of current-consuming and current-producing devices is brought up at this time so as to impress you with the fact that a certain voltage designation, such as a 115-volt lamp, in current-consuming devices, does not mean that the lamp is producing 115 volts, nor that if you put it on a circuit of any voltage, that it is getting 115 volts; but it simply means that the 115-volt lamp is designed to be operated on a circuit of exactly 115 volts. The voltage rating of a current-producing device does mean, however, that the device produces just that amount.

Series Circuits. There are two methods of connecting electrical devices for the forming of circuits. Let us go back to the dry cell for an illustration of this. Suppose you took four of the common dry cells—the kind used on door bells for example. If you connected them together with a wire running from the carbon or center terminal of one cell to the zinc or outside terminal of the other, and so on until all four were connected, as shown in Fig. 1, you would

have these cells connected in **series.** Wires from the two vacant binding posts, one from each of the end batteries in the connection, will form the mains to furnish the power. Let us get something of an idea of how this arrangement has affected the volts and amperes, or rather the pressure and current factors of this power group. A voltmeter connected across the mains from this cell group will show six volts. Six divided by the number of cells used, which in this case is four, will give $1\frac{1}{2}$, the voltage of each cell. The voltage of the circuit is therefore the added voltage of all the cells used. This would be true if you had any number of cells in your combination. One hundred cells would produce $100 \times 1\frac{1}{2}$, or 150 volts of pressure,

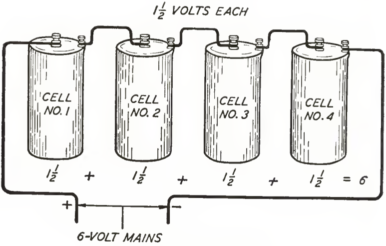


Fig. 1. Dry Cells Connected in Series

if connected as these are, in series. However, the capacity of each cell to produce and maintain current is so small that even though you had 150 volts you could not operate much of a circuit with it, for while you have the united pressures of all the batteries with this connection arrangement, you still have only the current-producing properties of just one cell.

In this series connection of four cells we have the combined pressures of all the cells but the current supplying power of one cell only. There is no current being generated in the batteries nor is there any current flowing through the line unless a complete elec-

trical circuit is made from one end battery to the other. If little resistance be offered by the complete electrical circuit, then a tremendous amount of current will flow and the battery will be exhausted in a short time; if there is much resistance in this complete electrical circuit then little current will flow. Again we have use for Ohm's Law in selecting the load and should carefully choose devices of the proper voltage rating for operation on a circuit of this power. *The voltage rating of a current-producing device is the statement of the pressure produced by that device, while the voltage rating of a current-consuming device is a statement of how much pressure there is to be between the two wires connected to that device.* This rating of current-consuming devices is determined by the resistance built into the device and is worked out with Ohm's Law by the manufacturer building that device.

Having selected a lamp of suitable voltage for operation in the circuit, we can connect it directly across the mains from these four cells, Fig. 1, and it will operate satisfactorily. We must not expect that these four cells can keep on supplying current to this lamp for an indefinite period, for dry cells are not intended for continuous operation, but for intermittent service. When used intermittently, they have some chance to recuperate slightly between the calls placed upon them to supply power, and their life is thereby lengthened. The only path for the current to travel in this series connection of which we are studying is through each and every device in the circuit. *Therefore the current through each device in a series circuit is the same,* like the flow of water through the pump, pipes, and tanks, Fig. 2. This simple statement holds as true for current-consuming devices which may be connected in the circuit as for current-producing devices. If we want to measure the electric current flowing through an electrical circuit we place an ammeter in the electric circuit and the meter will measure the current flowing through itself, which will be the current of the circuit.

We have seen how the voltage of a group of dry cells, forming a current-producing device when connected in series is the voltage of the sum of the separate members of the group. Now this method of voltage calculation holds as true when current-consuming devices are assembled in a series circuit for operation from a source of current supply.

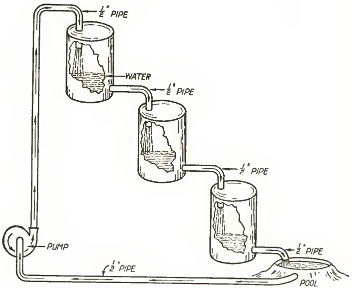


Fig. 2. Flow of Water Through a Series of Pipes and Tanks

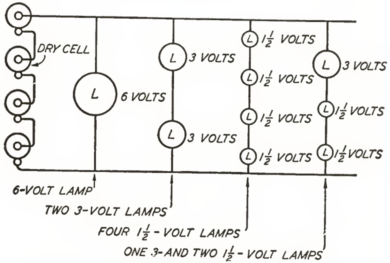


Fig. 3. Method of Connecting Lamps of Different Voltages So They Can Be Operated from the Same Set of Dry Cells

The correct voltage rating for devices to be operated on the four dry-cell group of 6 volts, was 6 volts and we can operate one 6-volt lamp on that circuit, Fig. 3, or two 3-volt lamps in series, or four $1\frac{1}{2}$-volt lamps in series, as we choose. We could even put on a combination of one 3-volt and two $1\frac{1}{2}$-volt lamps, all in series, if we had need of it. The only thing we need to watch in our arranging of combinations is that the sum of the rated voltages of these lamps equals that of the rated voltage of the source of power to which the group is to be attached. This method of connecting low voltage lamps in series for operation on circuits of higher voltages is illustrated in the string of Christmas tree lights now common on

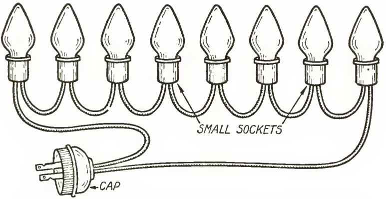


Fig. 4 Method of Wiring 15-Volt Christmas Tree Lamps So They Can Be Operated from a 115-Volt Lighting Circuit in the Home

the market, Fig. 4. If the house circuit to which they are attached is 115 volts and the number of lights in the string is eight, it is easy to calculate the voltage of each lamp by the following problem.

$$115 \div 8 = 14\frac{3}{8} \text{ or } 14+$$

Therefore 14+ would be the number of volts for each lamp.

It is also possible to group different types of devices on circuits of higher voltages than that on the name plates of the devices, but it is rarely successfully done with regard to efficiency. This is often quite confusing to the student, because he does not always grasp the fact that the devices in that type of circuit do not at all times have across them the voltage for which they are rated, nor do they

get the current required for their successful operation. As an example, take a toaster and a lamp each rated to operate on 55 volts; this voltage is just about half of the voltage for the house lighting circuit and at first glance it would seem all right to connect them in series, Fig. 5, and place them across the 110-volt or 115-volt house mains by inserting the plug in the wall outlet. Let us try the connection. The light will operate very brilliantly indicating that it is getting more than its share of the voltage and the toaster will not even redden up. This is because the toaster requires four or more amperes for correct operation and cannot get it in this connection

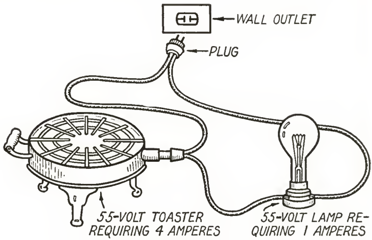


Fig. 5. Electric Toaster and Lamp Connected in Series
They will not work satisfactorily because the resistances are not the same.

because the lamp will pass only its rated current or a little more. You might see this more clearly if we took as an illustration a water pipe line made of a one-inch pipe with a section of $\frac{1}{4}$-inch pipe placed into the middle of the line as shown in Fig. 6. In this pipe line there would be only as much water flow out of the 1-inch pipe as would pass through the $\frac{1}{4}$-inch pipe.

The $\frac{1}{4}$-inch pipe offers a higher resistance to the flow of water than does the 1-inch pipe, and in the same manner the lamp connected in series circuit, Fig. 5, will offer more resistance to the flow of current than will the toaster.

Objections to Series Circuits. There are many objections to the use of series connections for lighting circuits. The chief of these being that as the current flows in turn through each lamp, should one lamp burn out or be turned off, then the circuit is opened and all the lights go out. If your house were to have all the lamps connected in a series circuit as shown in Fig. 7, no one could turn out a light until all the people affected were ready to have all the lights put out. Then too, your lamps would have to be of low

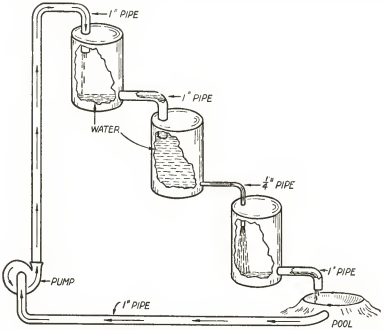


Fig. 6. Diagram Showing How a Small Pipe Controls the Amount of Water that Can Flow Through the Tanks, Pumps, and Larger Pipes

enough voltage so that the sum of the voltages of all of them would be that of the voltage delivered to your house by the Electric Light Company. This would call for the manufacture and sale of lamps of many different voltage-ratings and the buyers of these lamps would almost have to be electricians to be able to calculate the combinations needed for each house.

It has come to the point now in the development and standardization of electrical devices, that about all the use for series circuits

as far as lighting is concerned is in street lighting, Fig. 8. In this case there is no need to turn off one lamp before the others are turned off, and because of the higher voltage which may be supplied to the line with the resultant lowering of line loss, this style of circuit can be successfully employed.

As was stated before, it is possible to rearrange our dry cells in the circuit so that the group of connected cells will have the ampere capacity of the entire group rather than the capacity of one cell, as is the case when the cells are connected in **series.** The connection

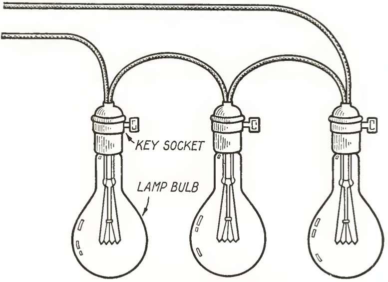


Fig. 7. Method of Wiring Three Lamps in Series

of these cells to effect this increase in capacity is done only with a sacrifice of the voltage gained by the series connection. Keep in mind that it is possible to connect a group of cells for an increase in volts **or** an increase in ampere capacity, not **both** at the same time and with the same connection.

Parallel Connection. In Fig. 9, the water is at the same height in each of the tanks, therefore the pressure from each is the same, and the pressure from one tank does not add to that of another. However there is four times the amount of water flowing from the group as from one tank.

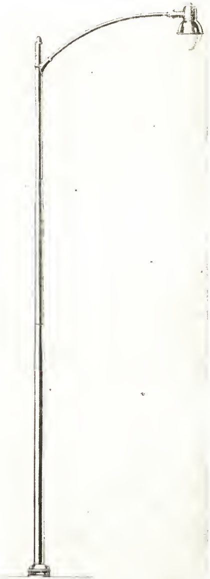


Fig. 8. Modern Street Lamp
Courtesy of Joslyn Mfg. and Supply Co., Chicago, Ill.

If a group of cells is joined so that all the center terminals are connected to one line and all the outside terminals to the other line, Fig. 10, the cells are said to be connected in **parallel.** This connection furnishes the voltage of one cell to the line, but gives the group the capacity in amperes of the sum of all the cell capacities. In the case of the group of cells, it does no more than make this cell group

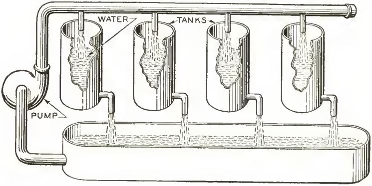


Fig. 9. Four Tanks in Parallel
Total pressure that of one tank. Total flow of water, four times that from one tank.

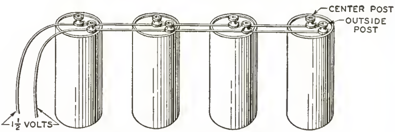


Fig. 10. Four Dry Cells Connected in Parallel.
Voltage output (1½ volts) is same as voltage of one cell; current output is four times that of one cell.

into one large cell, for if you had one large cell with the zinc and carbon surface areas of all the cells composing the group, you would get the identical performance.

In this parallel cell-connection the voltage of each cell is the same as the line voltage, so it would not do to put cells of different voltages—as for example, the one dry cell of 1½ volts, placed in parallel with a storage cell whose voltage is always 2 volts per cell

as shown in Fig. 11. In this case you would have a local circuit set up between the cells, and part of the energy of the cell with the most voltage would be consumed in forcing current through the one of the smaller voltage, thereby detracting some of this energy from the line. Now it would be quite all right to connect in this parallel circuit a group of dry cells which varied in size or ampere capacity, for the possible amperes of the entire circuit would be the sum of the possible capacities of all the cells.

Let us consider *current-consuming* devices rather than *current-producing* devices in the parallel type of connection. If, for example, we should use lamps in this hook-up, they must be rated the same

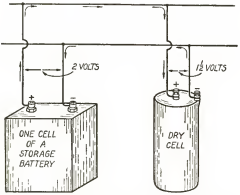


Fig. 11. Attempting to Parallel Cells Producing Different Voltages Causes a Flow of Current As Shown by Arrows

as the line voltage on which they are to be used. If the line is 6 volts, then all the lamps must be rated for 6 volts, or at least, something approximating that voltage. The ordinary automobile lamp in common use is rated at 6-8 volts. This is because that while the battery voltage is 6, the generator which is on the line and charging the battery when the engine is in motion must have a pressure of something in excess of this 6 volts, in order to be able to force current into the circuit against the pressure exerted by the battery. The 8-volt value is then the generator voltage, and is also the voltage of the line when the generator is in action. This explains the reason for the dual lamp rating, although the lamp itself is probably constructed for near 8-volt operation so as to get its maximum life.

However, if you are considering a line of 115 volts, as in the house lighting circuit, across which you wish to place your lamps in parallel, then the lamps should have a rating approximating 115 volts. Lamps with lower ratings than that—there are 105-volt lamps on the market—when placed across this 115-volt line, will burn somewhat brighter than those constructed to operate on 115 volts, but will have shorter lives. Lamps of ratings higher than this, 125-volt lamps being quite common, last much longer, but do not burn up to brilliancy. These latter ones are sometimes used in

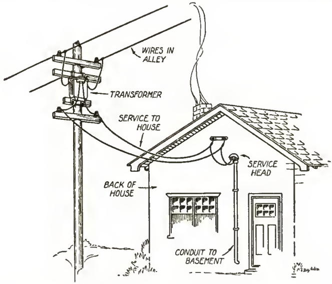


Fig. 12 Method of Supplying Electric Current to a House
Voltage between top wires on pole 2300 volts to 4000 volts or higher. Transformer changes voltage to 115 volts between service wires to house.

inaccessible places where replacements are difficult and advantage is then made of their lengthened life.

Voltage Drop in House Lighting. Lights and other devices which are to be placed in parallel on a circuit must be of a voltage at least approximating that of the circuit. It would be better if they were of the exact circuit voltage. However, due to the fact that there is line resistance always present there is then a loss in voltage in any circuit and this is commonly known as a **line drop.** See Fig. 12.

The resistance of the wires over which the current travels to get to the house is sufficient to cause a voltage loss. The pressure when the lamps are reached is not as much then as the pressure of the circuit at the transformer. Thus various points in a circuit are then sure to differ slightly in voltage from the source of power until the end of the line is reached where the voltage is the lowest. In modern house wiring, this voltage drop is usually so small it is not considered at all.

If the devices are all of the same voltage, which is the line voltage, we might assume that in parallel circuits the voltage is **equal** and **constant.** There is no reason, however, for keeping all of the devices on a parallel circuit of the same size, or ampere rating, and so these separate pieces of apparatus that are for use on a parallel circuit may be of sizes that differ widely as to ampere capacities. You may have an electric iron, for instance, with its current-consumption rate of 4 to 5 amperes connected across the same circuit with a lamp using $\frac{1}{4}$ ampere, and the two devices will both function perfectly. These two devices each use a different amount of current, however, in the two branch circuits, although both are connected to the same circuit wires. The current through the mains at the meter is increased by the addition to the circuit of each lamp or device. Therefore, the total current through the mains of a parallel circuit is equal to the sum of the current through each of its separate branches or parts.

We have discussed the relations in each of these series and parallel connections of the voltages of the separate parts of the circuit and we have also discussed the relations to each other and to the circuit voltages. Again we have discussed the relations of the current in the separate parts of the circuit to the current in the main circuit. We have not however discussed the resistance relations. We know that each circuit has some resistance in its make-up; we also realize that there must be sufficient resistance built into the devices of the circuit. That is they must have the proper voltage rating to hold back all but a workable amount of current from rushing through the circuit and overheating it, thereby ruining the devices and the wiring. This condition is commonly known as a **short circuit** or a **short** and its existence is more often the result of an accident such as a break down in insulation, than by intention,

Fig. 13. A short circuit **always** has **serious** results as far as equipment goes. Since resistance is so closely related to the voltage rating of devices, we can, in series circuits, treat the resistances of the separate parts just as we treat the voltages of those same parts. Hence, the resistances of a series circuit is equal to the sum of the resistances of its separate parts just as the voltage of the series

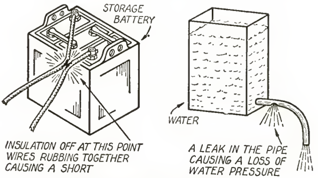


Fig. 13. Illustrating a Short Circuit
A leak in the pipe provides a short route for the water.

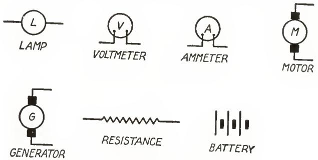


Fig. 14. Symbols Used in Electrical Circuits

circuit is equal to the sum of the voltage drops across the separate parts.

Let us summarize these facts before we take up for discussion the resistance of parallel circuits.

Series Circuits. The **voltages** of the separate parts are **added** to get the entire circuit voltage.

The **resistances** of the **separate** parts are **added** to get the entire circuit resistance.

The current is the same in different parts of the same circuit and equal to the total voltage across the terminals of the circuit divided by the sum of all the resistances of that circuit.

Parallel Circuits. The **voltages** are all the same—**constant.**

The total **current** is equal to the **sum** of the currents through each branch.

The resistance can usually be found by the formula $R=\frac{E}{I}$.

You saw that in a parallel circuit when more devices were added to the circuit the ampere load of the circuit as a whole was increased. According to Ohm's Law, which is $R=\frac{E}{I}$ the same voltage is pushing a greater current through the circuit as a whole, even though resistance in the form of additional branches is being

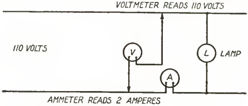


Fig. 15. Method of Connecting Voltmeter and Ammeter in Circuit

added. As the voltage is constant and is not being changed, the value of E of the above formula is not being changed; but the increase in current due to other devices being added to the circuit does increase the value of I in the formula. With the increase of this denominator of the fraction the result being obtained by the division of the unchanging value of E by I, will be smaller as the value of I is increased.

Applying Ohm's Law to Circuits. In order to show you how to make use of Ohm's Law, so that you can find out some other facts about the electrical circuit it will be necessary to give you several of the following practical problems.

Problem 1. What is the resistance of a lamp that allows 2 amperes of current to flow through it when connected to a 110-volt line?

NOTE:—It will help you to see the problem if you will make a sketch, like the one shown in Fig. 15, using the symbols given in Fig. 14.

Solution

Instruction

There are 2 amperes through the lamp and a pressure of 110 volts across it.

The letter R represents the resistance, and resistance is found by dividing the pressure by the current, or by the formula $R=\frac{E}{I}$.

In this case $E=110$ and $I=2$. You are required to find R.

Operation

$$R=\frac{E}{I}=\frac{110}{2}$$

$$110 \div 2=55 \text{ ohms}$$

which equals the resistance of the lamp.

Problem 2. In Fig. 16 another lamp like the one in the previous sketch is added to the circuit. This lamp draws also 2 amperes.

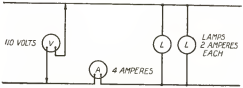


Fig. 16. Two Lamps Connected in Parallel on the Same Circuit

Then the ammeter will show that another lamp is added to the circuit by showing a reading of 2+2 or 4 amperes.

Now as each lamp draws just 2 amperes, then the resistance of each lamp will be as shown in the previous explanation, or $\frac{110}{2}=55$ ohms.

The resistance for the whole circuit, however, will be as follows:

Solution

Instruction

The ammeter shows 4 amperes. The voltmeter shows 110 volts. The resistance is the voltage divided by the amperes or $R=\frac{E}{I}$.

In this case $E=110$ and $I=4$. You are required to find R.

Operation

$$R=\frac{E}{I}=\frac{110}{4}=27\tfrac{1}{2} \text{ ohms}$$

the resistance of the whole circuit with 2 lamps.

This then shows that when the load on a parallel circuit is doubled, the resistance of the complete circuit (not of individual members of the circuit) is halved.

In Fig. 17 there are four devices connected in series, with the resistances of each and the current of one given.

In solving any one of these problems, the first thing is to determine whether or not the circuit is series or parallel. Then refer back to the methods of treatment of the different circuit-factors under the heading series or parallel. In this problem it is easy to see that this circuit is series. Also, the only data given in the problem for **each** of the devices in the circuit is the resistance data. There is, however, a current value for one device. Under the rules for the treatment of these different current factors found under the series heading, it will be noted that resistances in series are to be

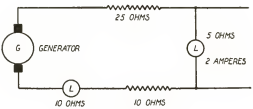


Fig. 17. Series Circuit

added to find the total resistance of the circuit. You will also see that the current is given for one resistance only, reference to the tabulated information will show that the current through a series circuit is the same through each device; then if you know the current through one device you know that amount is the current value through all or any part of the entire circuit. With this information and the use of Ohm's Law it is quite possible to calculate the unknown values for any part or for the entire circuit. The only thing that will have to be watched is that when you are using Ohm's Law for the entire circuit, be sure that you are using values that pertain to the entire circuit and not to one individual part which has no bearing on the values of the entire circuit. Also when dealing with the individual devices, do not use the values pertaining to the entire circuit.

Problem 3. What is the voltage drop across a 5-ohm lamp (Fig. 17)?

Solution

Instruction	*Operation*
This lamp has given for it also the value of the current as 2 amperes. The method of finding voltage when the resistance and the current are known is to use $E=IR$.	$E=IR$ $E=2\times 5=10$ volts across the lamp.

Problem 4. What is the current of the circuit (Fig. 17)?

Solution

Instruction

This is a series circuit, and in series circuits the current throughout the circuit is the same. We have a value of 2 amperes given for the 5-ohm lamp, therefore the current through each and every part of the circuit must also be two amperes. This gives us the current value for the other parts as well, and an additional factor for the solution of our problems.

Problem 5. What is the current of the 25-ohm resistance (Fig. 17)?

This is answered in Problem 4.

Problem 6. What is the total resistance of the circuit (Fig. 17)?

Solution

Instruction	*Operation*
The resistance of a series circuit is the sum of the separate resistances of that circuit.	$25+5+10+10=50$ ohms of the circuit.

Problem 7. What is the voltage supplied by the generator (Fig. 17)?

Solution

Instruction	*Operation*
You have the current of the circuit from Problem 4 which is 2 amperes. You have the resistance from Problem 6 which is 50 ohms. Then the pressure is found by $E=IR$.	$E=IR$. $E=2\times 50=100$ volts across the circuit which must be the generator voltage.

Problem 8. In Fig. 18, each lamp draws $\frac{1}{2}$ ampere and the generator voltage is 110. What is the voltage across each lamp?

Solution

Instruction

In parallel circuits, the voltages are all supposed to be the same, and as you have a generator voltage of 110 volts given, this must also be the lamp voltages.

Operation

Generator voltage is 110. Lamp voltage is the same $=110$.

Problem 9. What current is flowing through the entire circuit (Fig. 18)?

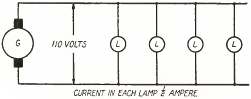


Fig. 18. Four Lamps Connected in Parallel

Solution

Instruction

Looking up current in parallel circuits will show that the current of the entire circuit is the sum of the current of the separate parts. Each lamp here will take $\frac{1}{2}$ ampere.

Operation

$\frac{1}{2}+\frac{1}{2}+\frac{1}{2}+\frac{1}{2}=\frac{4}{2}$ or 2 amperes, which is the current of the entire circuit.

Problem 10. What is the resistance of each lamp (Fig. 18)?

Solution

Instruction

The resistance of a lamp or device is found by dividing the voltage across it (110) by the current through it ($\frac{1}{2}$).

Operation

$R=\frac{E}{I}$ or $R=E\div I$.

$R=110\div\frac{1}{2}$ is $110\times\frac{2}{1}=220$ ohms, the resistance of each lamp.

Problem 11. What is the resistance of the entire circuit (Fig. 18)?

Solution

Instruction

This is found by dividing the pressure of the circuit (110 volts) by the current of the circuit (Problem 9 shows this to be 2 amperes).

Operation

$R=\frac{E}{I}=\frac{110}{2}=55$ ohms, the resistance of the circuit.

REVIEW QUESTIONS

1. If four 1½-volt dry cells were connected in *series*, what would the resultant voltage be? What effect would the series connection have on the current capacity?

2. What are some of the disadvantages of series-connected lighting circuits? Under what conditions may series wiring be employed for a lighting circuit?

3. If four 1½-volt dry cells were connected in *parallel*, what would be the resultant *voltage?* The *current capacity?*

4. Why is it permissible to connect several current-consuming devices of different current ratings to a parallel circuit?

5. What would be the result of attempting to parallel two cells or batteries of different terminal voltages? What would happen if they were connected in series?

6. A resistance of 10 ohms and a resistance of 20 ohms are connected in series across a 120-volt source. How much current will flow through the combined resistance?

7. Six lamps rated at ½ ampere each are connected in parallel across a 110-volt power source. What is the total current drawn from the source? The voltage across each lamp? The resistance of each lamp? The resistance of the combination?

8. What is the result when the insulation on the two wires of a 115-volt circuit wears off or breaks down and permits the bare conductors to touch each other? What happens to the current? The voltage?

9. A voltage of 30 volts at a low current drain is required. You have an unlimited number of 1½-volt dry cells on hand. How many would you need and how would you connect them?

10. Make a simple sketch showing how you would connect a voltmeter to measure the terminal voltage of a 110-volt generator supplying current to light bulbs connected in parallel. Indicate where you would place an ammeter to measure the current drawn by the four lamps.

APPLICATIONS TO INDUSTRY

1. How many lights are connected on the usual series string of Christmas-tree lights? What is the voltage across each light if the string is connected to a 110-volt line? If two extra lights are connected in series with the others, what effect would it have on the brilliance of the lights? What would be the voltage across each light?

2. Four lamps rated at ½-ampere each at 32 volts are connected in series. What should the voltage output of a generator be to light each lamp to normal brilliance? What will be the current demand upon the generator?

3. If you have a toaster rated at 110 volts and 4 amperes and a light bulb rated at 110 volts and 2 amperes, and the only voltage available is 220 volts, could you satisfactorily connect the two in *series* across the 220-volt line? What would be the result?

4. If the ½-ampere lamps in Fig. 18, page 127, were replaced by lamps each having a resistance of 55 ohms, how much current would the 110-volt generator have to deliver to the lamps?

5. How are the cells in a 6-volt automobile storage battery connected? How many are there?

6. What would be the effect of placing an electric iron rated at 220 volts at 5 amperes across a 110-volt line? Would the iron overheat? Underheat? Draw more current than its rating? Less current?

7. Would it be advisable to connect a lamp rated at 110 volts directly across a 220-volt line? Why?

8. How would you connect a 110-volt, 5-ampere electric hotplate to a 220-volt line if all you had were a number of 1-ampere light bulbs? Draw a sketch.

9. Why is an automobile headlamp light bulb rated at 6 to 8 volts although the battery may have a terminal voltage of only 6.3 volts maximum?

10. Would you get the same voltage from a wall outlet as you would from the leads of the pole transformer supplying the house? Why?

ASSEMBLING A MODERN SWITCHBOARD PANEL USED TO CONTROL ELECTRIC POWER IN ARSENALS, AIR BASES, PLANTS AND SHIPS

Courtesy of Westinghouse Electric and Mfg. Co., East Pittsburgh, Pa.

DIRECT-CURRENT METERS

Direct-current instruments are fundamentally current measuring devices; their indications or "calibration" depending on the characteristics of the meter. An outside view of a direct-current ammeter is shown in Fig. 1. The outside general appearance of

Fig. 1. Outside View of Ammeter
Courtesy of Weston Electrical Instrument Corporation

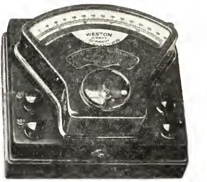


Fig. 2. Outside View of Voltmeter
Courtesy of Weston Electrical Instrument Corporation

the direct-current ammeter is nearly the same as that of the direct-current voltmeter shown in Fig. 2.

A view of the principal working parts of a direct-current voltmeter is illustrated in Fig. 3. An enlarged and more detailed view

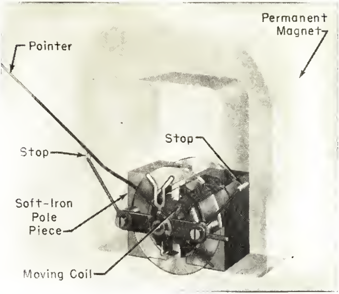


Fig. 3. Interior Construction of Weston Direct-Current Voltmeter

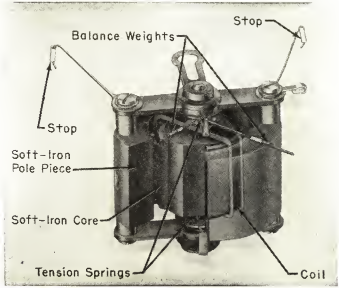


Fig. 4. Detail Construction of Magnet and Moving Coil

of the construction of the moving coil and magnets is shown in Fig. 4.

These meters consist primarily of a permanent magnet and a moving coil. It is the force set up in the moving element, due to the effect of the permanent magnet field on the current flowing through the moving coil, which causes deflection and gives an indication of the current or voltage being measured. Instruments of this kind are used for measuring direct currents only.

PERMANENT MAGNETS

Magnets. One of the most important factors in a direct-current instrument is the permanent magnet. Upon the strength of this magnet depends the accuracy and sensitivity of the instrument. A great deal of study and research has been expended to develop magnets as used in present day meters.

It has long been known that iron and steel are the most highly magnetic substances. The problem was to produce a magnet of high strength and of uniform or permanent strength. Some materials retain magnetism better than others. The softer and purer a piece of iron, the greater the amount of magnetism which can be developed in it, but the shorter will be the time it will retain this magnetism after the magnetizing force is withdrawn. Cast iron and hard steel will not allow nearly as much magnetism to be developed in them, but they retain magnetism for a much longer time after the removal of the magnetizing force. This ability of metals to retain magnetism is known as **retentivity.**

For the greatest sensitivity of the instrument the magnet should be as strong as possible. However, strength is not the only thing to be considered for it is well known that so called permanent magnets gradually lose their strength, that is they **age.** The aging depends upon the quality of the steel, the design of the magnetic circuit and upon the temperature variations and mechanical jarring to which the magnet is subjected. After a sufficiently long period of aging the magnet reaches a nearly permanent state. Sufficient natural aging would require that the magnets be magnetized and then stored for a long period of time which is an expensive process. Since any deterioration will influence the accuracy of the instrument the magnets are aged by resorting to artificial means.

Artificial aging may be obtained by one of the following methods. After being fully magnetized the magnet may be heated in a steam bath for four or five hours; partially demagnetized by passing alternating current through a coil surrounding the magnet, or by mechanically vibrating the magnet. Of these the alternating-current method is most used to-day.

Magnets for less expensive instruments are sometimes made of cast iron while higher grade instruments use special magnet steel. The strength of aged cast-iron magnets is less than the strength of those of equal weight made of special magnet steel.

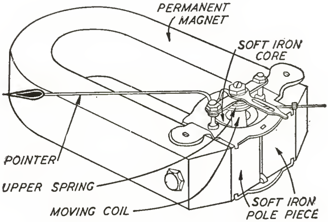


Fig. 5. Interior Construction of Jewell Direct-Current Meter

The particular shape of the magnet depends largely on the manufacturer, but they are all of the horseshoe type. Figs. 3 and 5 show the magnets and moving elements used in the Weston and Jewell direct-current instruments. The Weston instruments are made by the Weston Electrical Instrument Corporation, Newark, New Jersey, and the Jewell instruments by the Jewell Electrical Instrument Company, Chicago, Illinois.

Magnetic Field. Let us now consider the magnetic field developed by an instrument magnet. If a piece of paper be laid over a permanent magnet and a light covering of iron filings sprinkled on it the iron filings will arrange themselves parallel with the lines of force of the magnetic field. This gives a very convenient way of

studying magnets. Fig. 6 shows the field pattern of an instrument magnet made visible by iron filings.

Lines of force radiate from the magnet in all directions. Only those passing directly between the poles are of service in the operation of the instrument. However, such a distribution of the lines of force does not serve our purpose as you will see later.

The next step in the construction of the magnetic system is the addition of pole pieces attached to the ends or poles of the magnet, Fig. 7. You will now notice that the addition of these pole pieces has the effect of concentrating the magnetic lines that we wish to use. and that they form a ring on the faces of the pole pieces. Yet

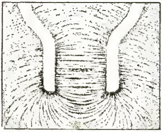


Fig. 6. Lines of Force of a Weston Permanent Magnet

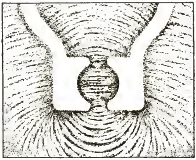


Fig. 7. Lines of Force of a Weston Permanent Magnet with Pole Pieces

there are some lines in the center which are still parallel and have not taken a uniformly radial position such as is desired.

The radial position of these lines is the ideal that is sought since it gives us a concentrated and uniform field throughout the path of rotation of the moving coil. To obtain this uniform or radial field a cylindrical core of soft iron is inserted.

Fig. 8 shows the distribution of the lines of force with the pole pieces and a soft iron cylindrical core in place. We can now see that a uniform radial field has been obtained.

To permit freedom of rotation of the moving coil within this radial magnetic field the air gap between the core and pole pieces must be established accurately. The air gap for an average instrument is made about 0.05 inch ($\frac{5}{100}$ or $\frac{1}{20}$) in width; that is, the annular space between the pole piece and core through which the

moving coil travels is 0.05 inch wide, a little less than one sixteenth ($\frac{1}{16}$) of an inch.

Since there is practically a uniform field established in the air gap through which the moving coil rotates, it follows that the deflection of the coil and pointer will be proportional to the current in the coil and the instrument will have a uniformly divided scale;

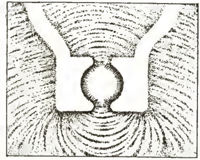


Fig. 8. Lines of Force of a Weston Permanent Magnet with Pole Pieces and Soft Iron Core

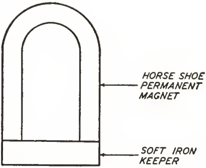


Fig. 9. Horseshoe Magnet with Keeper

that is, the divisions on the scale representing increase in current strength will be evenly spaced so far as the eye can discern.

Another point of importance about this magnet is the method used to assure its permanency. A magnet which is supplied with a keeper, as shown in Fig. 9, or a piece of soft iron placed across its poles, will retain its magnetism longer than with no keeper. When this keeper is properly designed the magnetism will be retained un-

impaired indefinitely, as it provides a path of low reluctance for the lines of force.

You will recall that the distance between the pole piece and core was made very small (0.05 inch) and that the pole piece and core were each made of soft iron, so you can readily see that the effect of these parts is to provide the magnet with a keeper. In other words, the air gap is so small that it does not disrupt or impede the path of the lines of force to any appreciable extent, and enables the magnet to retain its permanency throughout an indefinite period of years.

MOVING COIL

Electromagnets. If a compass be brought into the neighborhood of a single conductor carrying an electric current, the needle deflects thus indicating the presence of a magnetic field. This magnetic field, or flux, exists in circles about the conductor as shown in Fig. 10. These circles have their centers at the center of the

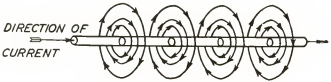


Fig. 10. Direction of Lines of Force around a Wire

conductor and their planes are perpendicular to the conductor. If the current in the conductor be reversed, the direction in which the compass needle is deflected is reversed also showing that the direction of this magnetic field is dependent upon the direction of the current.

An experiment shown in Fig. 11 illustrates the concentric relation of the flux to the current-carrying conductor. A conductor is passed vertically through a horizontal piece of cardboard. Iron filings sprinkled on the cardboard, while current is flowing through the conductor, form concentric circles. (A current of about 100 amperes is necessary to obtain distinct figures.) If four compasses were placed as shown, they also would indicate, by the direction in which their needles point, that the magnetic lines are circles having the axis of the wire as a center.

Relation of Magnetic Field to Current. A definite relation exists between the direction of the current in a conductor and the direction of the magnetic field surrounding the conductor. Perhaps the simplest way of defining this relationship and the easiest way to remember it is by means of the **right-hand rule.**

Right-Hand Rule. Grasp the conductor in the right hand with the thumb pointing in the direction of the current flow. The fingers will then point in the direction of the lines of force, Fig. 12. If the

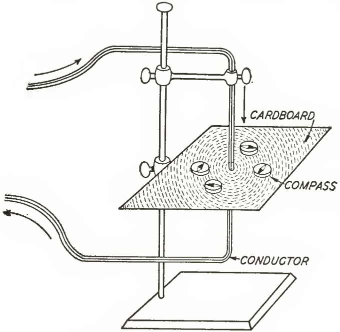


Fig. 11. Lines of Force around a Conductor

current be reversed, and the wire grasped with the thumb pointing in the other direction, you will see that the direction of the flux around the wire has also changed.

Magnetic Flux or Field about Two Parallel Conductors. When each of two parallel conductors carries an electric current, flowing in the same direction, there is a tendency for the two conductors to be drawn together. In the left-hand part of Fig. 13 the lines of force encircle each conductor in the same direction and the resultant field is an envelope of lines tending to pull the conductors together.

This is due to the fact that the magnetic field always tends to conform itself so that the maximum amount of flux is attained.

Parallel Turns. If these two parallel conductors were placed close together their resultant field would be similar to that of a single conductor carrying twice the current of one of the parallel conductors.

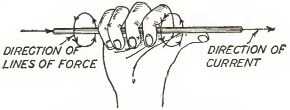


Fig. 12. Application of the Right-Hand Rule

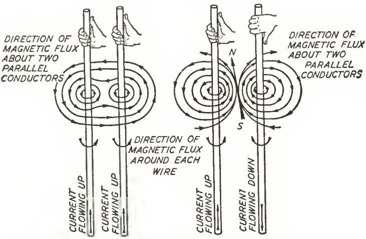


Fig. 13. Direction of Lines of Force about Two Parallel Conductors with Current Flowing in the Same Direction and in Opposite Directions

The condition which exists when two parallel conductors carry current in opposite directions is shown in the right-hand part of Fig. 13. The magnetic lines are circles, but these circles are not concentric either with one another or with the conductor. When the conductors are separated, the area through which the flux passes is increased, so that the magnetic circuit in this case tends to separate the conductors and thus conforms itself so that the magnetic flux is a

maximum. A decided south and north pole will be found directly in front and back of the two parallel conductors.

Magnetic Field of a Loop. If a wire carrying a current were bent into a loop, a field similar to that shown in Fig. 14 would be obtained. Opposite sides of this loop may be termed parallel conductors with the current flowing in opposite directions. This magnetic field has a north pole and a south pole which possess all the properties of similar poles of a short bar magnet. A compass needle placed in this field assumes the direction shown, the north pole pointing in the direction of the magnetic lines.

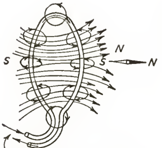


Fig. 14. Magnetic Field Produced by a Loop of Wire

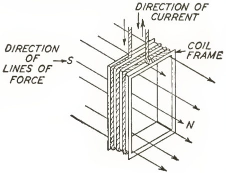


Fig. 15. Magnetic Field Produced by a Meter Coil

The magnetic field of this loop may be increased by the following two methods; first by increasing the current through the loop, and second by increasing the number of turns or parallel conductors.

The magnetic field of a coil is directly proportional to the number of turns times the current through the coil. Since in the case we are considering, that of the moving coils of instruments, the number of turns of the moving coil is fixed by the mechanical dimensions. This rule may be stated as follows: *The magnetic field strength of the coil is directly proportional to the current through the coil.* That is, when the current through the coil is doubled, the field strength is doubled. When the current is increased to four times its original value the field strength is also increased four times. Thus a measure of the field strength of the moving coil is a measure of the current flowing through the coil.

Principle of Direct-Current Instruments. If a coil like that shown in Fig. 15 carries a current, a magnetic field results with a north and a south pole at opposite ends of the coil. If the coil carrying current be placed in a magnetic field, the coil will tend to turn in such a direction that the resulting magnetic field due to both the main field and that of the coil will be a maximum. Also the north pole of the coil will be attracted toward the south pole of the magnet, and the south pole of the coil will be attracted to the north pole of the magnet.

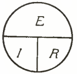
The moving coil of a direct-current instrument, Fig. 4, is made of several turns of wire carefully insulated and wound upon a rectangular aluminum frame. This coil is supported at the top and bottom by hardened steel pivots turning in cup-shaped jewels, usually sapphire. The jeweled bearings are carried by non-magnetic yokes attached to the pole pieces in such a manner that the coil is truly centered. This method of supporting the moving coil is almost frictionless. The current is led in and out of the coil by two flat spiral springs, as shown in Fig. 4, of non-magnetic material, one at the top of the coil and the other at the bottom. These springs are also the means of measuring the force exerted by the current through the moving coil. When current flows through the moving coil, the effect of its magnetic field upon that of the permanent magnet field is to cause the moving coil to rotate to a position where the force due to the field of the coil is just equal to the returning force of the springs. The top and the bottom springs are coiled in opposite directions so that the effect of change of temperature, which causes a spiral spring to coil or uncoil, will not cause the needle to leave its zero position. A very light and delicate aluminum pointer, Fig. 3, is attached to the moving element to indicate the deflection of the coil. This is carefully balanced by small counterweights so that the whole moving element holds its zero position very closely, even if the instrument is not level. The pointer moves over a graduated scale which may be marked in volts or amperes as the case may be. Because of the uniform radial field the deflection of the moving coil in this type of instrument is practically proportional to the current in the moving coil so that the scale of the instrument has substantially uniform graduations.

Damping. If the moving coil, which is mounted on jeweled bearings, starts to swing, it will continue swinging back and forth similar to a pendulum for some time, unless it is in some way retarded or *damped.* One method of damping is to attach an air vane to the coil. This air vane is enclosed so that it swings in a restricted space and damps any swinging movement of the coil. The most satisfactory method is electrical damping. If the coil be wound on an aluminum bobbin the motion of the bobbin through the magnetic field will induce magnetic currents within itself, and these will be in such a direction as to put an electric load on the moving coil. This opposes the motion of the coil and thus brings the pointer to rest at the value to be read.

An instrument for test work should be well damped but not over damped. The pointer of an over damped meter is very slow in reaching its position of rest, while the pointer of a properly damped instrument moves very quickly and comes to rest with only about two or three over swings. Not only does proper damping give faster readings, but these slight oscillating swings serve to assure the user of the instrument that there is no friction present.

Direct-Current Instruments. From the foregoing we have learned that the deflection of a direct-current instrument is a measure of the current passing through it. The field of the moving coil tends to rotate the coil to include as much of the flux from the permanent magnet as possible. This motion is opposed by the phosphor-bronze springs.

Direct-Current Voltmeter. A standard Weston voltmeter moving coil has a resistance of 5 ohms and requires 0.01 ampere ($\frac{1}{100}$) for full-scale deflection. Ohm's law states that, *the voltage between two points in a circuit equals the current multiplied by the resistance.* Or, as an equation,



Voltage (E) = Current $(I) \times$ Resistance (R)

or, simply, $E = I \times R$

In the problem under consideration,

Current $(I) = 0.01$ ampere for full-scale deflection

Resistance $(R) = 5$ ohms

Voltage $(E) = I \times R = 0.01 \times 5 = 0.05$ volts or 50 millivolts for full-scale deflection

One Volt = 1000 millivolts

By full-scale deflection we mean the needle points to the highest value marked on the scale. Full-scale deflection on the instrument scale shown in Fig. 3 is 150 volts.

A single dry cell furnishes 1.5 volts. Such a source would furnish thirty times the voltage required to produce full-scale deflection and would wreck the moving coil if applied to it. To adapt it for higher voltages, resistance must be connected in series with the moving coil. If we wanted 1.5 volts to give full-scale de-

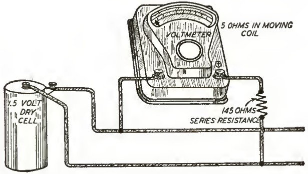
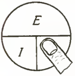


Fig. 16. Resistance Connected in Series with Voltmeter. In actual construction, this resistance is placed inside the meter case.

flection we should put enough resistance in series to give 0.01 ampere. The resistance of the moving coil and series resistance should be



$$R=\frac{E}{I}=\frac{1.5}{0.01}=150 \text{ ohms}$$

Since the moving coil itself has 5 ohms resistance an additional resistance of 145 ohms is necessary. The circuit would then look like Fig. 16. In actual practice the resistance material is mounted inside the meter case and is connected in series with the moving coil. The other end of the 145 ohm resistance is connected to the positive binding post.

A voltmeter for measurements on standard direct-current lighting circuits of 115 to 125 volts has a full-scale deflection of 150 volts. As before 0.01 ampere is necessary for full-scale deflection. The resistance necessary to obtain this current is found as follows:

$$R=\frac{E}{I}=\frac{150}{0.01}=15{,}000 \text{ ohms}$$

A total resistance of 15,000 ohms is required in a voltmeter having a range of 150 volts. Of this 5 ohms is in the moving coil and 14,995 ohms in the resistance unit contained within the instrument.

Instruments of this kind are made with resistances contained within their case for ranges of full-scale deflection up to 300 volts.

USE OF METERS

Multipliers. Whenever possible the series resistance is contained within the case of the instrument. When, due to require-

Fig. 17. Portable Resistor or Multiplier for D.C. Voltmeter
Courtesy of Jewell Electrical Instrument Company

ments for better insulation on higher voltages, or lack of space, more resistance is required than can be contained within the instrument case, resistance boxes or multipliers are used, Fig. 17. On each multiplier, as shown in Fig. 17, is stamped the number of the voltmeter it is intended to be used with. When using voltmeters with separate multipliers, particular care must be taken to see that each instrument is used with its proper multiplier as a multiplier resistance must be an exact multiple of the voltmeter itself. The term multiplier is applied to voltmeter resistors because there is usually a multiplying factor to be applied to the instrument readings. For

instance, a 300-volt voltmeter when connected in series with its 600-volt multiplier gives full-scale deflection of 600 volts. Since the full-scale reading is marked 300 volts a multiplying factor of 2 must be used. That is, the reading indicated by the voltmeter needle, must be multiplied by 2 for the correct value.

Fig. 18 shows the construction of a voltmeter multiplier. The resistance wire is wound on mica cards as shown. This gives a unit convenient to mount and insulate, also a unit of high resistance and low inductance. By properly spacing the mica cards and enclosing

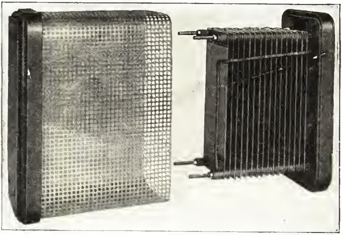


Fig. 18. A Weston Multiplier or External Resistor
Courtesy of Weston Electrical Instrument Corporation

the resistor in a perforated metal case overheating of the units is prevented.

Use of the Voltmeter. The voltmeter is intended to measure the voltage between two points, that is between the two points connected to the meter terminals. This must always be kept in mind when using the instrument that proper readings may be obtained.

Figs. 19 and 20 show the method of connecting direct-current voltmeters. When the full-scale deflection of the instrument is greater than the voltage to be measured, the connection shown in Fig. 19 is used. If the voltage to be measured is greater than the full-scale deflection of the instrument, a multiplier must be used in series with the voltmeter as shown in Fig. 20.

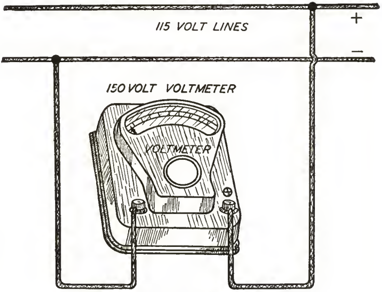


Fig. 19. Connection of Voltmeter to a Circuit

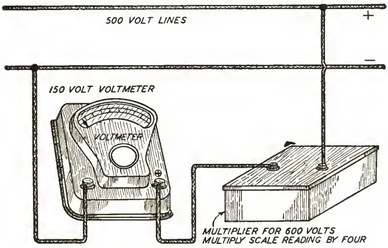


Fig. 20. Connection of a Voltmeter with Multiplier

Voltmeters are very delicate and sensitive instruments and must always be handled with care. Mechanical shocks or jars will injure the jeweled bearings, and too great a voltage will wrench the

moving coil and bend the delicate pointer, even if the voltage is not much larger than that intended to be measured by the instrument.

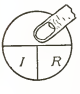
Direct-Current Ammeter. Modern direct-current ammeters consist of a voltmeter and an accurately adjusted resistance known as a shunt. The voltmeter indicates the voltage drop across the shunt and has its scale marked off in amperes.

Voltmeters designed to use with shunts for current measurements usually have a full-scale deflection of 50 millivolts (0.05 volts) and are therefore named millivoltmeters. The scales of these instruments however are not marked in millivolts but in amperes corresponding to the full-scale deflection obtained when measuring the voltage drop across the shunt carrying rated current.

We again find the principle of measurement based upon Ohm's law. In the previous work we have studied the voltmeter and seen how it is constructed to indicate voltages of various parts of a circuit. As an ammeter the millivoltmeter deflection is proportional to the voltage drop across a precisely adjusted resistance or shunt. This is in accordance with the statement of Ohm's law which says: *The current in amperes passing through a resistance is equal to the voltage drop (volts) across the resistance divided by the value of the resistance (ohms).*

As an illustration, let us consider Fig. 21 which shows a shunt and millivoltmeter having a full-scale deflection of 1000 amperes. 1000 amperes through the shunt which has a resistance of 0.00005 ohm will produce a voltage drop of 0.05 volt.

$$E = IR = 1000 \times 0.00005 = 0.05 \text{ volt}$$



This voltage will cause full-scale deflection of the millivoltmeter. If the instrument has 100 scale divisions, Fig. 22, every division represents ten amperes ($1000 \div 100$) of current in the main line.

Shunts of various ranges may be employed with the same instrument. If we substitute for the 0.00005 ohm shunt, another shunt having 10 times the resistance, or 0.0005 ohm, 100 amperes will produce a drop in potential of 0.05 volt and bring about a full-scale deflection of the millivoltmeter.

$$E = I \times R = 100 \times 0.0005 = 0.05 \text{ volt}$$

The range of this instrument is now 100 amperes instead of 1000 and every scale division represents one ampere.

Next replace this shunt with another having a resistance of 0.005 ohm. Ten amperes will cause a drop in potential of 0.05 volt in such a shunt and produce a full-scale deflection.

$$E = I \times R = 10 \times 0.005 = 0.05 \text{ volt}$$

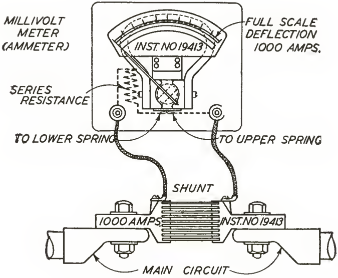


Fig. 21. Connection of Millivoltmeter and Shunt

Fig. 22. Ammeter Scale

Each scale division now corresponds to 0.1 of an ampere and the range of the instrument is 10 amperes. It will thus be seen that the same millivoltmeter may be used to indicate a full-scale deflection with either 10 amperes, 100 amperes or 1000 amperes, depending upon the shunt employed with it.

While it is true that in divided circuits each branch passes a portion of current inversely proportional to its resistance, and it is to be expected that a portion of the main line current will go through the instrument, while the remainder only goes through the shunt. As a matter of fact the portion of current which the instrument takes is so small that for all practical purposes it may be assumed that the entire main line current goes through the shunt. The millivoltmeter, therefore, simply has to measure the fall in potential across the shunt.

Ammeter Shunts. Ammeter shunts are not marked according to their resistance but according to the amount of current required to produce 0.05 volt drop across their millivoltmeter terminals. The shunt shown in Fig. 21 is marked 1000 amperes. This indicates that a current of 1000 amperes passed through the shunt will produce full-scale deflection of the millivoltmeter. Besides being marked with its current rating, each shunt also bears an instrument number which corresponds with the instrument number on the millivoltmeter with which it is intended to be used. The ammeter shunt lead wires, Fig. 21, employed in the calibration of an instrument with any shunt, should always be used with that shunt for the fall in potential encountered, due to the resistance of the wires which enters into the deflection obtained on the instrument with a given current. If a high voltage was being employed a small change in this resistance would make little difference, but due to the fact that only 0.05 volt (50 millivolts) is used in the entire circuit, any alteration in the resistance of the leads would alter the deflection obtained with a given current in the shunt. The leads are usually about six feet long. They must never be lengthened or shortened after the instrument is once calibrated and adjusted, for to do so would throw the instrument out of calibration and cause it to give a false reading.

Construction of Ammeter Shunts. The shunt is usually made of manganin strip brazed to comparatively heavy copper blocks, as shown in Fig. 23. Two sets of terminals are fastened to the copper blocks. The heavy terminals are for carrying the main current through the shunt. The small terminals are used to connect the ammeter leads. The heavy copper blocks serve two purposes. They are excellent conductors of heat, so carry the heat away from

the manganin strip, and their low resistance keeps all parts of each copper block at nearly the same potential. Several strips of manganin are used for large shunts in preference to a single piece so as to more readily radiate the heat generated. Portable shunts and switchboard shunts are similar, except that the portable shunts are mounted on wooden bases to protect them from injury. Fig. 24 shows various sizes of both types of shunts.

Water Analogy of a Direct-Current Ammeter. A clear conception of the operation of an ammeter may be obtained by means of a water-main analogy. The pipe or water main *AA*, Fig. 25, through which water is flowing under pressure, as in city water mains, may be compared with the conductor or bus bar *FF*, Fig. 26. The pipe section *B* of reduced diameter corresponds with the shunt *E*, and the

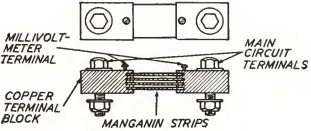


Fig. 23. Construction of a Shunt

small pipes *CC* may be compared with the ammeter leads *GG*. It is obvious that, since the meter pipes *CC* are of smaller dimensions than the water main *AA*, less water will flow through them. As long as the proportion between the water passing around through the meter *D* and that passing through the water main is constant, the quantity of water flowing through the meter will depend upon the total quantity flowing through the water main. Therefore, the meter may be calibrated to indicate the total flow of water instead of merely indicating the quantity passing through the small pipe.

On the same principle, the scale of the instrument may be figured to indicate any required amperage. But although the current through the shunt may be 20,000 amperes or more, the sensitivity of the instrument is so great that only about 0.03 ampere is required to give full-scale deflection, and under proper conditions no

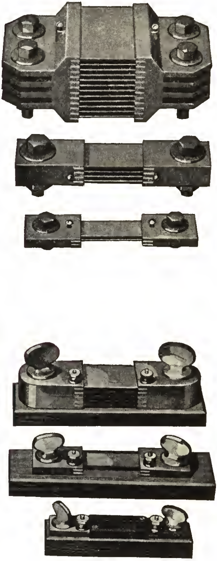


Fig. 24. Switchboard and Portable Shunts
Courtesy of Jewell Electrical Instrument Company

current in excess of this amount will ever pass through the instrument. The ammeter leads together with the movable coil and resistors inside the instrument case are so proportioned that the flow of current through the instrument is limited to the proper amount. But, nevertheless, instead of merely indicating the amount

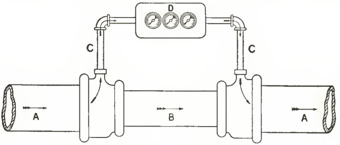


Fig. 25. Water Main or System
Courtesy of Weston Electrical Instrument Corporation

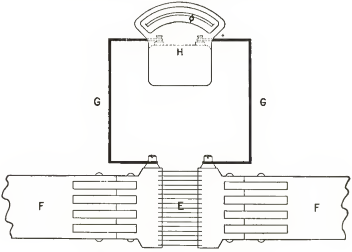


Fig. 26. Electrical Bus Bars and Shunt

of current passing through its movement, the ammeter scale may be calibrated to correctly indicate the total current flowing through the shunt.

Finally, the quantity of current which will flow through the instrument will depend upon the resistance of the shunt. Therefore,

since shunts of different resistances and current capacities may be used in place of the shunt shown, the instrument may be used for an unlimited number of ampere ranges.

Self-Contained Ammeters. Sometimes for convenience direct-current ammeters are made for just one range of full-scale deflection

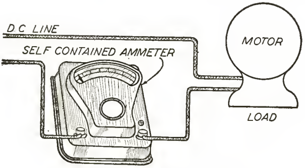


Fig. 27. Connection of Ammeter in Motor Circuit

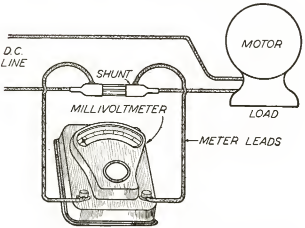


Fig. 28. Connection of Millivoltmeter and Shunt in Motor Circuit

and have the shunt contained within the instrument case. These instruments are more convenient to handle than millivoltmeters with separate shunts, but are not as flexible in use. Fig. 27 shows the method of connection of ammeters having self-contained shunts in a circuit in order to find the amount of current taken by the motor.

Use of the Ammeter. The ammeter is intended to indicate the current flowing through a circuit. To measure current the shunt is connected in series in the line to be checked. Fig. 28 shows a millivoltmeter and shunt connected to measure the current taken by a motor.

Ammeters, like voltmeters are very delicate and sensitive instruments and must be handled with care at all times. Mechanical jars and shocks will injure the jeweled bearings. A current greater than the amount giving full-scale deflection will wrench the moving coil and bend the delicate pointer. A careless connection such as placing

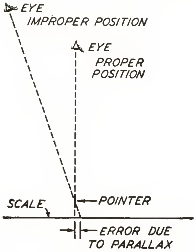


Fig. 29. Method of Reading Meters Correctly

the shunt directly across the lines, like a voltmeter connection, may completely destroy both the shunt and the instrument.

Always be sure to select a shunt you know to have a greater capacity than the estimated current that is to be measured.

Switchboard Instruments. Instruments for switchboard mounting contain the same type of permanent magnet and moving coil as the portable instruments we have been studying. The only real difference is in the cases used on the types of instruments. Since switchboard instruments must be read from some distance they are usually made larger and have scales with much larger figures and less divisions.

Parallax. In some instruments there is a strip of mirror, Fig. 3, placed below the pointer, and at the inner edge of the scale. These instruments are intended for accurate reading and should be read by looking directly down on the instrument, placing the eye so that the image of the pointer is hidden by the point itself. The reading can then be taken without the error due to parallax. Fig. 29 shows what is meant by the parallax error. An easy experiment to prove this error may be made by using a clock. Stand directly in front of the clock when the minute hand is near the hour six or twelve and note the hand's position with reference to the dial. Now walk to one side and again note the time indicated. You will see that the correct time is only to be read when standing directly in front of the clock.

REVIEW QUESTIONS

1. Of what does a *direct-current meter* primarily consist?
2. What causes deflection of the pointer to give an indication?
3. In high-grade instruments, what type of magnet is used?
4. What is the purpose of *artificial aging* of meter magnets?
5. Sketch simply the field pattern of a simple instrument magnet.
6. For what purpose are pole pieces added to the ends or poles of an instrument magnet?
7. In what way does the soft-iron cylindrical core serve to retain the strength of the instrument magnet?
8. Why must the magnetic field through which the meter coil rotates be uniform?
9. What is the relation between the strength of a magnetic field about a conductor and the value of current flowing through the conductor?
10. By means of the right-hand rule, how would you determine the direction of the lines of force about a conductor if you knew the direction of current flow through the conductor?
11. Draw a simple sketch to show the magnetic field pattern existing about two parallel conductors when the currents flowing through them are in the same direction. In opposite directions.
12. What two factors determine the strength of a magnetic field about a coil conducting a current?
13. Describe briefly the principle of operation of a direct-current meter.
14. What is the purpose of *damping* in a meter, and what are two common methods employed?
15. What is the purpose of a *multiplier?* Of a *shunt?*

APPLICATIONS TO INDUSTRY

1. If you attempted to measure the voltage from an alternating-current outlet in your house with a permanent magnet direct-current meter, what would the result be? Why?

2. What is the purpose of the heavy terminals on the ends of ammeter shunts?

3. Draw a simple diagram to show how you would connect an ammeter having a self-contained shunt to determine the current taken by a motor connected to a generator.

4. A Weston voltmeter has an internal resistance of 5 ohms and gives full-scale deflection at .01 amperes. What would be the full-scale deflection in volts?

5. In the Weston voltmeter of question 4, what would you do to permit the measurement of voltages up to 10 volts? Up to 100 volts? Up to 1,000 volts?

6. What type of instrument is used for switchboard mounting?

7. How may voltmeters be used to serve the function of ammeters?

8. Why must the length of shunt leads of an ammeter never be changed after the meter is once calibrated?

9. Make a sketch to show how you would connect a voltmeter with an external multiplier, and an ammeter with an external shunt to measure the voltage supplied and the current drawn by a 115-volt motor connected to a generator.

10. Why is it necessary to have a wide variety of ammeter shunts or voltmeter multipliers? Why not use the largest multiplier and the heaviest shunt to read everything from the lowest to the highest values?

ALTERNATING-CURRENT METERS

Use of Alternating Current. Over ninety per cent of the electrical energy generated at the present time is generated as alternating current. This is not due to any superiority of alternating over direct current in its application to industrial or domestic uses. In fact, there are many instances when direct current is absolutely necessary for industrial purposes, but even in these cases the energy is often generated as alternating current.

Some of the reasons for generating energy as alternating current are as follows:

1. Alternating current may be generated in large quantities much cheaper than direct current.
2. Alternating current may be generated and transmitted at high voltages. These high voltages can be reduced efficiently at the receiving end of the transmission line to voltages suitable for lights or motors with small loss. The voltage of direct-current circuits cannot be changed economically so the power must be generated and transmitted at low voltages.

For constant speed work, the alternating-current motor is cheaper in first cost and in maintenance than the direct-current motor. This is due to the fact that the induction motor has no commutator.

Since alternating current may be purchased more cheaply than direct current, we find it applied to almost every purpose possible. The study of alternating-current meters is therefore one of great importance.

Cycle and Frequency. An electric current which flows back and forth at regular intervals in a circuit is called an alternating current. When the current rises from zero to a maximum, returns to zero and increases to a maximum in the opposite direction and finally returns to zero again it is said to have completed a cycle. This cycle of changes is repeated over and over again. The number of times this cycle takes place in one second is called the frequency of the current. Thus a current which rises to a maximum in each

direction 60 times a second is said to make 60 cycles per second, or have a frequency of 60.

The cycle of alternating current must be thoroughly understood before its effects as related to meters can be studied.

Water Analogy. The nature of electricity is at present discussed in vague terms of electrons, ions, and charged particles. The underlying fundamental reasons for its existence are not yet thoroughly understood; yet the flow of electricity along a wire is very much like the flow of water in a pipe. Direct current we liken in principle with the flow of water in a river.

As already stated alternating current flows back and forth at regular intervals. We may liken the flow of an alternating current to the ebb and flow of the tide in a narrow channel. Of course

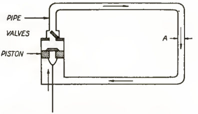


Fig. 1. Pipe Circuit Containing a Pump with Valves
It corresponds to a direct-current electrical circuit.

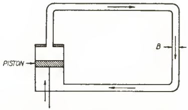


Fig. 2. Pipe Circuit Containing a Valveless Pump
It corresponds to an alternating-current electrical circuit.

the frequency of such a tidal flow would be extremely small. Some ideas of the nature of direct currents and alternating currents can be derived from the study of Figs. 1 and 2.

Fig. 1 represents a pipe circuit containing a pump with valves so arranged that the water in the pipe flows in one direction only independently of the piston motion. This is the water analogy to a direct-current system. The pipe takes the place of the wires, and the pump of the generator. The valves of the pump represent the commutator of the generator. Both valves and commutator allow the current to flow in but one direction.

The pump in Fig. 2 has no valves. The direction of the current in the pipe therefore depends upon the direction of the piston motion. The pump without valves represents a generator without a commutator. Such a generator would deliver an alternating current to the line.

Let us assume that the pumps shown in Figs. 1 and 2 operate through one cycle each second. That is, the pistons starting from the positions shown travel up toward the top of the page until their limit of travel is reached, then their motion is reversed and they travel down to their lower limit of travel and then return to the position shown, in one second.

The amount of water flowing past point A in Fig. 1 in one second is equal to the amount of water displaced by the piston in one stroke. A meter designed to indicate water velocity would at this point indicate the average velocity of the water.

At the first thought it might seem that the value in amperes of an alternating current should be based on the average value. However, if the variation of current over one complete cycle is considered, the average value is zero as there is just as much negative as positive current. Referring to Fig. 2 we see this is also true for our water analogy. During the up-stroke of the piston, exactly the same amount of water passes B in one direction as passes in the opposite direction, during the return stroke. The average amount of water passing point B is zero.

Alternating-Current Ampere. The value of an alternating current is not based on its average value but on its heating effect and may be defined as follows:

An alternating-current ampere is that current which, flowing through a given ohmic resistance, will produce heat at the same rate as a direct-current ampere.

Heating is proportional to the watts dissipated. Since the equation for watts is current squared (or times itself) multiplied by the resistance, the alternating-current ampere is proportional to the square of the current. An alternating-current meter must therefore have a deflection proportional to the current squared.

Difficulties of Alternating-Current Measurements. A direct-current ammeter if connected to measure an alternating current would indicate zero, as such an instrument reads average values. This is due to the fact that the moving coil which carries the current to be measured is placed in a permanent magnet field. Since the field of a permanent magnet remains constant and in the same direction at all times, the moving coil attempts to go in one direction during one-half of the cycle and in the reverse direction during

the other half of the cycle when the current reverses. As the current is equal and opposite during the two halves of the cycle the direct-current meter indicates zero. A direct-current meter of the permanent magnet type cannot therefore be used to measure alternating current. In order to make an instrument of the moving coil type for alternating currents it is necessary to replace the permanent magnet by an alternating-current magnet operating on the same frequency as the current in the moving coil.

Alternating-Current Electromagnets. Direct current passing around a wire loop sets up a steady field as indicated by the arrows in Fig. 3. If now the current around the loop be reversed, so as to travel around the loop in the opposite direction from that shown,

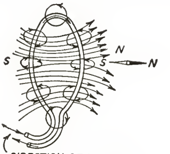


Fig. 3. Magnetic Fields Produced by a Loop of Wire

the direction of the magnetic field also reverses. Alternating current passing through this loop will produce a field which reverses every time the current reverses.

Damping of Alternating-Current Instruments. Damping as applied to alternating-current instruments fulfills two purposes, namely: to prevent rapid vibration of the movable element due to the alternating-current frequency; and to bring the movable element quickly to rest, so that no time need be lost in the taking of readings.

Theoretically, perfect damping is obtained when the movable element is brought to rest without overswing, in the shortest possible time. This condition is not usually fulfilled in practice, because of the possibility of the existence of slight friction in the instrument. The movable element is permitted to overswing a slight amount after which it is brought to rest. Damping of this character assures

the user of the instrument of the absence of friction, causing him to have greater confidence in the indications.

In the section on "Direct-Current Meters" we learned that direct-current instruments were damped magnetically, due to the currents generated in the aluminum bobbin of the moving coil in the field of the permanent magnet. Since alternating-current instruments do not employ permanent magnets, other methods must be used. Practically all alternating-current instruments in use today are provided with air dampers. This type of damping is described in connection with movable iron instruments.

Electrodynamometer Instruments. When current is caused to flow in a conductor there is set up about the conductor a magnetic

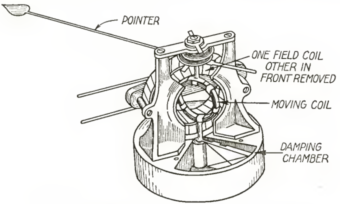


Fig. 4. Meter Element of a Jewell Dynamometer Type Instrument
Courtesy of Jewell Electrical Instrument Company

field which is proportional to the strength of the current flowing. If two conductors carrying currents are placed near each other, but not parallel, the magnetic fields about them will react upon each other in such a manner as to tend to become parallel.

The reacting force will be proportional to the fields about the conductors and, therefore, to the product of the currents in the conductors. The reaction is communicated to the conductors as a force tending to place them in a position parallel to each other.

In the electrodynamometer instrument, Fig. 4, the conductors are replaced by the field and movable coils. The field coils are held in a fixed position. The movable coil is pivoted so that its only

possible motion is that of rotation. It is placed directly between the two field coils. Figs. 5 and 6 show diagrammatically the connections. When current is caused to flow in both the field and movable coil circuits the movable coil will tend to rotate, the tendency being to place itself parallel to the field coil. The force causing this rotational motion is counter-balanced by the mechanical force exerted by two springs attached to the movable coil staff. When a balance of forces occurs the movable coil motion is stopped and the coil retained in its new position until further change takes place in the movable coil, or field currents. By having the pointer attached to the movable coil staff and properly calibrating a scale over which

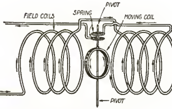


Fig. 5. Arrangement of Coils in a Dynamometer Type Instrument

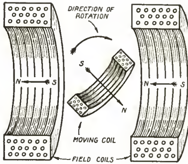


Fig. 6. Cross Section of a Dynamometer Type Instrument

the pointer will move, the instrument can be used for measuring the reaction effect of the coils upon one another.

These instruments are provided with knife edge pointers and scale plates having mirror slots to enable accurate readings to be obtained. The meter element is shielded from stray magnetic fields by a laminated iron shield which completely surrounds the movable coil and field coils. Electrodynamometer ammeters and voltmeters are the most sensitive and accurate of the common forms of alternating-current instruments.

Electrodynamometer Ammeters. The electrodynamometer ammeter, Fig. 7, is made in ranges from one to ten amperes and as milliammeters having ranges to as low as .015 ampere full scale. These instruments are usually made for two ranges. As there are

two field coils, one on each side of the moving coil they are arranged to be connected in series when the low range is used and in parallel when the high range is used. An instrument having a low range of one ampere full-scale deflection with the field coils in series has a high range of two amperes when the field coils are in parallel. The change of connection is made by means of two links located on the top of the instrument, as shown in Fig. 8. A study of Fig. 8 will disclose the fact that when the field coils are connected in parallel, as shown at A, half the current flows through each coil. When the

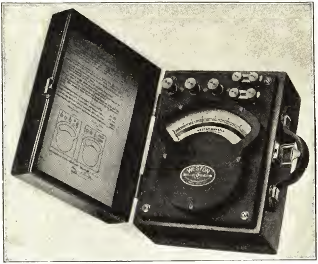


Fig. 7. An Electrodynamometer Ammeter
Courtesy of Weston Electrical Instrument Corporation

field coils are connected in series, as shown at B, the total current flows through each coil. Therefore, with the same amount of current flowing, the coils in series will be just twice as effective as when the coils are connected in parallel.

A resistance of proper value is connected in series with the field coils as shown in Fig. 9. This resistance is called a shunt. It is so designed that it is possible to utilize the entire resistance, or only a certain portion of it. When the field coils are arranged in series for low range readings, the entire shunt is used; in parallel for high range readings, only a portion of the shunt is brought into use.

Marked binding posts on the instrument top connect to the proper portions of the shunt.

The movable coil circuit is connected across the complete shunt and obtains its current from the drop produced by the current to be measured. The current to be measured passes through the field coils and through the parallel circuit consisting of the shunt and movable coil circuit.

The instrument depends upon the reaction produced between the field and movable coil circuits. The movable coil current being proportional to the shunt drop which is in turn proportional to the current to be measured, the torque of the instrument is proportional

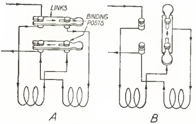


Fig. 8. (A) Parallel Connections of Links—High-Current Range
(B) Series Connections of Links—Low-Current Range

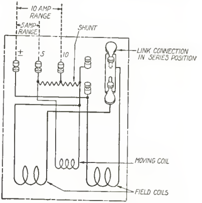


Fig. 9. Diagram of Connections of a Weston Electrodynamometer Ammeter

at any point of the scale to the square of the current flowing. Consequently the instrument indicates the true effective value of the current.

It is therefore essential that the current passing through the movable coil be the same for full-scale values of current applied to the instrument for both high and low ranges. This condition is achieved by making the resistance of the two portions of the shunt exactly the same.

The electrodynamometer ammeters as shown in Fig. 7 have double ranges, the higher range being twice the low range value. The combinations are 1-2, $2\frac{1}{2}$-5 and 5-10 amperes. The ranges may be extended by means of current transformers.

It is essential in using this type of instrument that the links used for changing the field coils for series or parallel connection be in the proper position. Connection diagrams and instructions are given in the cover of each instrument and should be carefully studied before connecting, and again referred to when checking connections.

Electrodynamometer Voltmeters. In the electrodynamometer type voltmeter, Fig. 10, the field coils are wound with many turns of a smaller size wire than is used in the ammeters. The field and movable coils are connected in series, as shown in Fig. 11, so that the full current required to operate the instrument passes through both.

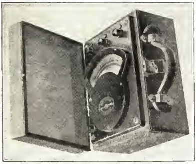


Fig. 10. Electrodynamometer Type of a Voltmeter
Courtesy of Weston Electrical Instrument Corporation

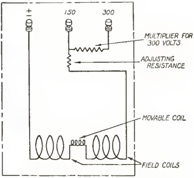


Fig. 11. Diagram of Connections of a Weston Electrodynamometer Voltmeter

Since the force exerted on the movable coil is proportional to the product of the current through the fields and the current through the moving coil, the deflection will be proportional to the square of the current and therefore the effective voltage. Fig. 12 shows a typical scale for a 150-volt electrodynamometer voltmeter. The arrow indicates a reading of 111 volts. This current is comparatively small varying with the range of the instrument, the lower the range the larger the current required by the instrument. Thus, for example, a one-volt instrument requires about 500 milliamperes and a 750-volt instrument about 30 milliamperes. Of course the coil windings, both as to conductor size and turns, will also depend on the range.

Care must be exercised in the use of voltmeters of this type, particularly those having ranges below 75 volts, as the current

required to operate them may cause a change in the normal condition of the circuit on which the instrument is used.

Multipliers (series resistances) are supplied for these voltmeters to extend their range to 750 volts. For higher ranges, potential transformers are used in conjunction with an instrument having a 150-volt range.

Movable Iron Instruments. Practically all alternating-current ammeters and voltmeters used for commercial measurements on electric light and power circuits are of the movable iron type. This type of instrument is cheaper, simpler, and more rugged than the electrodynamometer type although somewhat less accurate. The

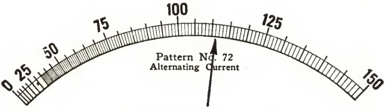


Fig. 12. Scale of a Dynamometer Type Voltmeter

principle of operation of the soft iron type of instrument is shown in Fig. 13.

At *A* in Fig. 13 we have two pieces of soft iron suspended vertically in a coil or solenoid by means of threads. There being no current flowing there will be no action between the iron pieces. The position of the coil at *B* shows the effect of passing a direct current through it. The direction of the current flow is such that the upper ends of the iron pieces are magnetized to be north poles and the lower ends of the iron pieces south poles. Since like poles of two magnetized bodies will repel one another, the iron pieces are forced apart. The position of the coil at *C* shows the same action but with the current reversed. If this reverse is sufficiently rapid the iron pieces will remain apart until the current flow is stopped. The position of the coil at *D* illustrates the coil placed horizontally with one piece of iron fastened so that it cannot move while the other piece is free to move. At *E* is shown the effect on this arrangement when current flows. The position of the coil at *F* shows the mov-

able iron piece attached so that it can move only by rotation. Thus when current is passed through the coil the movable piece will rotate on its staff and the pointer attached to it will move over the scale.

Rotation of the movable iron piece is opposed by a spiral spring. The force causing rotation depends on the strength of the magnetic field set up by the coil or solenoid. The field strength depends on the current flowing. Thus when current flows through the coil, the movable iron piece will rotate to such a position when the rotational force and spring force become equal. Motion then stops and the pointer position shows the scale value for the current flowing.

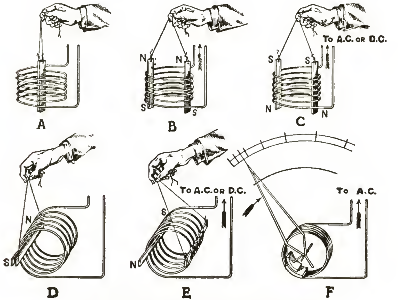


Fig. 13. Explanation of Principle of Movable Iron Instruments
Courtesy of Weston Electrical Instrument Corporation

Since both pieces of iron are magnetized by the same magnetic field, twice the current in the coil will produce twice the magnetism in *each* piece of iron. This results in a force of repulsion between the two members of four times the original. The deflection of a movable iron instrument is approximately proportional to the

square of the current and is therefore suitable for alternating-current measurements.

The actual marking of the scale may be varied somewhat by the shape of the stationary and movable iron parts, but all scales are compressed near the zero which is typical of all current squared instruments.

Fig. 14 shows a typical scale for a movable iron voltmeter having two ranges. The arrow indicates 116.5 on the lower scale or 233 on the upper scale.

Damping. Due to the lack of a permanent magnet and a moving coil with an aluminum frame such as we had in the permanent magnet direct-current instruments, magnetic damping is impossible. It is therefore necessary to create damping effects

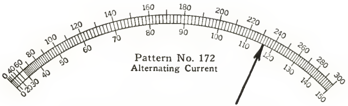


Fig. 14. Scale of a Typical Movable Iron Voltmeter

by some mechanical means. This is accomplished by means of an air damper box as shown in Figs. 15, 16 and 17.

The essential parts of the damper are a damper box and vane. The box (No. 5, Fig. 16) is a one piece casting having a recessed chamber in which the vane (No. 8, Fig. 16) moves. The chamber is closed by means of a cover plate (No. 6, Fig. 16) which practically causes a complete enclosure excepting a small opening on the inner edge of the vane to permit fastening the vane to the movement staff or spindle.

The vane consists of a thin sheet of light weight alloy. It is stiffened by ribs stamped into it and the bending of its edges which conform to the surfaces of the damping chamber. The vane is rigidly fastened to the movement spindle.

The movement of the vane is accompanied by compression of the air on the advancing side of the vane and by rarefaction of the

air on the receding side. The compressed air leaks through the small space made possible by the attachment of the vane to the movement spindle. The quality of damping depends on the degree of this air leakage. The leakage is controlled by properly proportioning the clearance space and the width of the turned-over edges.

Movable Iron Type Ammeters. Fig. 15 shows the construction of a movable iron type ammeter. The cover plate has been removed from the damper box to more clearly illustrate the damping mechanism. Fig. 16 shows the various parts used in the construction of the instrument. Thus in Fig. 16 (No. 3) is the coil or sole-

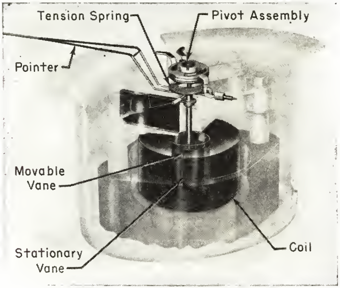


Fig. 15. Construction of a Movable Iron Type Ammeter
Courtesy of Weston Electrical Instrument Corporation

noid; (No. 8) is the movable iron piece attached to the pointer having the air-damper vane and controlling spring in place. Notice the movable iron piece is cylindrical in shape.

The relation of the fixed and movable pieces of iron is shown in Fig. 15. The fixed piece is secured to the extension in (No. 5) of Fig. 16. It is triangular in shape and is bent to be concentric with the movable piece. The uniformity of the scale depends on the shape of this fixed piece.

In an ammeter of this type all the currents to be measured pass through the meter coil. Thus in an ammeter having a full-scale deflection of 500 amperes, a coil of one turn of heavy copper bar is used. An ammeter designed to have a full-scale deflection of 1 ampere uses a coil having 308 turns of No. 20 B & S single silk covered wire.

The relation of the fixed and movable pieces of iron is shown in Fig. 17. The fixed piece is secured to the extension in No. 5 of

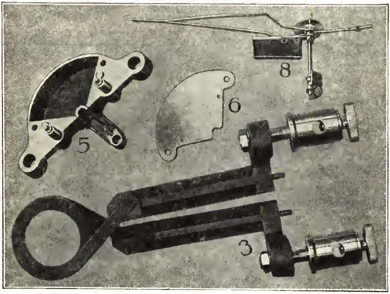


Fig. 16. Details of a Movable Iron Type Ammeter
Courtesy of Weston Electrical Instrument Corporation

Fig. 16. It is triangular in shape and is bent to be concentric with the movable piece. The uniformity of the scale depends on the shape of this fixed piece.

Shunts and Current Transformers. Shunts are not used in connection with alternating-current ammeters for several reasons. First, since the alternating-current instruments are not nearly so sensitive as direct-current instruments a satisfactory shunt would be called upon to supply a drop of several volts. This would make the shunt expensive and inefficient. Second, in alternating-current

circuits currents do not always divide according to Ohm's Law for ohmic resistances, due to the effect of inductance.

Where large alternating currents are to be measured, or where it is not desired to carry the line current to the ammeter, **current transformers** are used.

Movable Iron Type of Voltmeters. Fig. 18 shows a typical type of movable iron voltmeter the construction of which is shown similar to Fig. 17 in every respect except for the coil. The magnetizing coil or solenoid consists of a great many turns of small wire.

Voltmeters having ranges below about 100-volts full scale have special coils for each range. Instruments with ranges of 100 volts

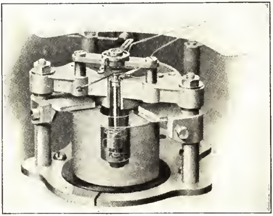


Fig. 17. A Phantom View of a Weston Movable Iron Type Voltmeter
Courtesy of Weston Electrical Instrument Corporation

or higher use similar operating coils with series resistances or multipliers to extend their range as explained in the section on "Direct-Current Meters." These series resistances may be calculated approximately by Ohm's Law (Resistance equals Volts divided by Amperes) but the exact amount of resistance must be determined by test when the instrument is calibrated.

Multipliers and Potential Transformers. Since alternating-current instruments require considerable power to operate, multipliers for higher voltages would have to be designed to carry relatively

heavy currents and would therefore be expensive to build. Due to the amount of current carried they would also be expensive to operate. On alternating-current systems this is easily overcome by the use of potential transformers.

Use of Movable Iron Instruments on Direct Current. These instruments are adapted for either alternating or direct current. Practically all instruments containing soft iron must be specially calibrated if used on alternating-current circuits. This is because of the hysteresis effect; that is, the lag in the magnetism of the iron behind the current producing it. Such instruments therefore, tend to indicate low on alternating currents as compared with equal direct-current values. This is because the magnetism does not

Fig. 18. Weston Movable Iron Type Instrument
Courtesy of Weston Electrical Instrument Corporation

have time to reach its maximum value before the current reverses, with alternating current applied. In modern instruments of the moving iron type where very small amounts of iron of high degree of purity are employed this reduces the hysteresis loss to a negligible quantity and the instrument indicates practically the same on both alternating and direct current. The instrument is not often used on direct current, however, because it is not as efficient nor as accurate as the permanent magnet type. In the direct-current instruments, described in the section on "Direct-Current Meters," the powerful permanent magnetic field acts as a fulcrum on which the moving coil exerts a great leverage with a very minute current.

No such field exists in the moving iron type shown in Figs. 15, 16, and 17, but the current itself must develop the magnetism which brings about the reaction between the moving and the stationary members. The result is that a 300-volt alternating-current instrument requires approximately six times the power to produce a full-scale deflection of that required for the permanent magnet instruments.

Inclined Coil Ammeter. Another type of movable iron instrument is the inclined coil ammeter. The moving element of this

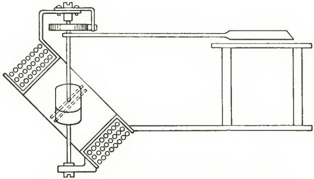


Fig. 19. The Moving Element of an Inclined-Coil Ammeter

meter is shown in Fig. 19, and is a light iron vane set at an angle of about 45 degrees to the spindle to which it is attached. The current flows through the coil which also is inclined at an angle of about 45 degrees to the spindle. When no current is passing, the plane of the soft iron vane makes a slight angle with that of the coil; on the passage of current through the coil the vane tends to place itself along the lines of force, that is, perpendicular to the plane of the coil. The deflecting force is nearly proportional to the current squared.

The voltmeter of this same type has the inclined disk replaced by a coil of fine wire connected in series with the stationary coil. This coil attempts to line its flux up with that of the stationary coil when voltage is applied at the terminals.

When two coils are used in this manner the instrument becomes one of the dynamometer type.

INDICATING WATT METERS

Watt. The watt is the unit of electrical power or rate of doing work. In direct-current circuits the power in watts is equal to the product of the volts applied and the current flowing in the circuit. One ampere times one volt equals one watt. In alternating-current circuits due to the presence of inductance the product of current times voltage must be multiplied by the power factor to obtain the true watts.

The indicating watt meter is used to measure the power in an alternating-current circuit.

Watt Meter. A watt meter is an instrument for indicating the instantaneous value of the power in an electrical circuit. It con-

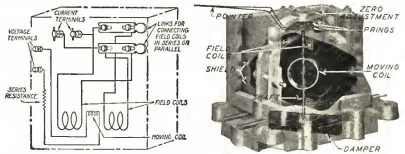


Fig. 20. Diagram of Connection and Internal Construction of an Electrodynamometer Type Watt Meter
(Right) Courtesy of Weston Electrical Instrument Corp., Newark, N. J.

sists of two members as follows: First, two field coils, Fig. 20, of coarse wire in series with the line, the strength of their field being proportional to the amperes passing. Second, a moving coil of fine wire connected in shunt with the line, the strength of its field being proportional to the potential difference of the circuit. It will be remembered that in a dynamometer instrument the force with which the moving member tended to turn was not due to the sum of the strengths of the separate fields in the two coils, but to their product. Now if the field of the field coils is proportional to the current in the line; and the field of the moving coil proportional to the voltage of the line; and if these coils are so mounted that they may interact on each other, the resulting tendency of the coils to turn is proportional to the product of their field strengths. The product of volts

and amperes is watts. Since the forces exerted by the coils are proportional to the instantaneous values of current and voltage, the true power is measured regardless of power factor. Hence, such an instrument will give a deflection which is proportional to the power in watts supplied to the circuit in which it is connected. The moving coil is mounted in jewel supports as is customary with a voltmeter. Current is admitted by means of phosphor-bronze spiral springs. An extra resistance is placed in series as in a voltmeter. The field coils are of sufficient cross-section to carry the entire current for the circuit in which they are connected. As in the electrodynamometer ammeter, Fig. 8, the field coils are so arranged that they may be either connected in series or parallel by means of links thus providing the instrument with two ranges.

Instrument Transformers. In the course of development of high-voltage alternating-current systems of transmission and distribution it has been found necessary to remove the various instruments from direct contact with the line circuits and to operate them at lower voltages by means of properly constructed transformers. This method of operation through transformers reduces to a minimum the possibility of personal injury.

Again, it is frequently necessary to meter very large currents in circuits of only moderate voltage. As it is highly desirable to avoid the expense of carrying heavy loads to the switchboard, current transformers are used.

By properly choosing the transformers, it is possible to use instruments designed for 5 amperes and 110 volts for measurements of all capacities. This not only reduces the danger but also the instrument cost and is now the accepted American practice.

Current Transformers. The current transformer, like the one shown in Fig. 21, is used in cases where very large alternating currents must be measured and also where current coils of instruments must be isolated for high-voltage lines. This enables lower range ammeters to be used than would ordinarily be required if the instrument were connected directly into the primary line.

The current or series transformer has a primary, usually of a few turns, wound on a core and connected in series with the line, Fig. 22. When the primary has a large current rating it may consist of a straight conductor passing through the center of a hollow

core, as shown in Fig. 23. The secondary, consisting of several turns, is wound around the laminated core. The ratio of current transformation is approximately the inverse ratio of turns. For example, if the primary has two turns and the secondary sixty turns, the ratio will be thirty to one. This means that the current in the primary is 30 times the current indicated in the secondary.

The secondaries of practically all current transformers are rated at 5 amperes regardless of the primary-current rating. For example,

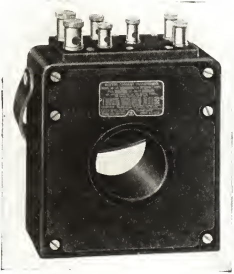


Fig. 21. Portable Current Transformer
Courtesy of Weston Electrical Instrument Corporation

a 2000-ampere current transformer has a ratio of 400 to 1 and a 60-ampere transformer has a ratio of 12 to 1. In the first case the current as indicated by a 5-ampere ammeter connected to the secondary of the 2000-ampere transformer would indicate 1 ampere when 400 amperes were flowing through the primary. A current of 3 amperes indicated by the ammeter indicates 3×400 or 1200 amperes flowing through the primary.

The current transformer differs from the ordinary constant-potential shunt transformer, used for lighting and power, in that

its primary current is determined entirely by the load on the line and not by its own secondary load. If its secondary becomes open-circuited, a high voltage will exist across the secondary because of the large ratio of secondary to primary turns causes the transformer

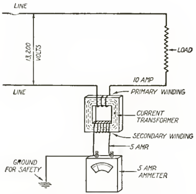


Fig. 22. Construction and Diagram of Connections of a Current Transformer

to act as a step-up transformer. This will result in heating of the transformer core as well as a high voltage across the secondary terminals. **Therefore a current transformer should always have its secondary short-circuited.**

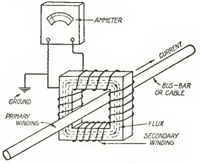


Fig. 23. Current Transformer of the "Through" Type

Potential Transformers. Potential transformers, like the one shown in Fig. 24, do not differ materially from the constant-potential transformers used on standard lighting and power circuits, except

that their rating is small. Below 5000 volts they are usually air-cooled, and above this they are usually oil-cooled, the oil being used more for its insulating qualities than for cooling purposes. As only instruments are connected to their secondaries, such transformers ordinarily have ratings of from 40 to 200 watts. The low-tension side is almost always wound for 110 volts and the ratio is then determined by the rating of the high voltage winding. For example, a 13,200-volt potential transformer would have a ratio of 13,200 divided by 110 or 120 to 1.

Fig. 24. Portable Potential Transformer
Courtesy of Weston Electrical Instrument Corporation

Fig. 25 shows a simple connection for measuring voltage in a 13,200-volt circuit by means of a potential transformer. The secondary should always be grounded at one point to eliminate static charges from the instrument and further to insure safety to the operator.

Instrument Transformer Connections. Fig. 26 shows the method of connecting a typical instrument load, through instrument transformers, to a high voltage line. The load on the instrument transformers includes an ammeter, a voltmeter, watt meter and watt-hour meter. Each secondary is grounded at one point. Correction

for ratio of transformation must be applied to all the instrument readings. The watt meter and watt-hour meter involving the ratio of both the current and the potential transformers.

Usually in permanent installations, as on switchboards, the instrument scales themselves are so marked as to take into consideration these ratios. Therefore, the primary power may be read directly. Where portable test instruments are used particular care must be taken to always apply proper ratios to the readings.

To illustrate the use of instrument transformers let us consider the values indicated in Fig. 26. The ammeter has a full-scale deflec-

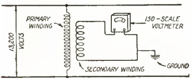


Fig. 25. Connections for a Potential Transformer

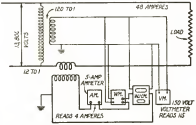


Fig. 26. Typical Connections of Instrument Transformers and Instruments for Single-Phase Measurements

tion of 5 amperes and is used in connection with a current transformer having a ratio of 12 to 1 or 60 to 5. If the ammeter reading is 4 amperes the line current is 4×12 or 48 amperes. The voltmeter has a full-scale deflection of 150 volts and is used in connection with a 120 to 1 potential transformer. A reading of 115 volts at the voltmeter indicates a line voltage of 115×120 or 13,800 volts. Since the watt meter and watt-hour meter are connected to both the transformers their readings must be multiplied by the product of the two transformer ratios. That is 12×120 or 1440.

REVIEW QUESTIONS

1. What are some of the advantages of alternating current?

2. What is a *cycle* of alternating current? What is the frequency? Explain what is meant by a 60-cycle current?

3. Upon what is the value of an *ampere of alternating current* based?

4. Why must an alternating-current meter have a *deflection* proportional to the current squared?

5. In an alternating-current meter, what is used in place of the permanent magnet of the direct-current meter?

6. What is the two-fold purpose of *damping* in alternating-current meters?

7. Explain the basic principle of the *electrodynamometer-type* of alternating-current meter.

8. Electrodynamometer ammeters usually have two ranges. How do you change from one range to another? What takes place when you do?

9. What essential differences are there between the electrodynamometer *ammeter* and *voltmeter?*

10. What are the advantages and disadvantages of the movable iron type of alternating-current meter?

11. Explain the basic operation of the *movable iron meter*.

12. What basic difference is there between the movable iron voltmeter and the ammeter?

13. Describe briefly the *inclined coil ammeter*.

14. Explain the basic operation of an indicating *wattmeter*.

15. Describe the purpose and principle of operation of a *current transformer*. Of a *potential transformer*.

APPLICATIONS TO INDUSTRY

1. Why are shunts not usually used on alternating-current ammeters? What is used instead?

2. Why must a current transformer always have its secondary short-circuited?

3. Draw a simple schematic diagram to show how you would connect an ammeter using a current transformer to a high-voltage circuit.

4. Make a simple sketch of a *voltmeter* using a potential transformer connected to a high-voltage circuit.

5. What is the essential difference between the way you connect a current transformer to a high-potential circuit and the way you connect a potential transformer to a high-potential circuit?

MEASUREMENT OF RESISTANCE

Care of Electrical Instruments. A mechanic is not only judged by the quality of his work but also by his tools and their condition. A man who takes good care of the implements of his trade must surely be a careful and skillful workman.

Measuring instruments will not stand a great amount of abuse. They must have reasonable care in order that they may give continuous service with the highest degree of accuracy. The following suggestions are worth the consideration of those who have anything to do with electrical instruments of any kind.

When instruments are not in use, they should be put away where they will be free from dust, oil, heat, moisture, and excessive vibration. A bookcase or a closed cabinet offers good storage space for instruments.

When not in use, all instrument cases should be closed, and instruments provided with separate cases should be kept in their containers. A great many glass instrument fronts have been broken because the instruments were left in a careless position and not protected with the facilities furnished by the manufacturer.

When using instruments intermittently over any extended period of time without disconnecting them, they should be properly covered with canvas to prevent the finely divided dust that is suspended in the air from filtering into the instrument cases and working into the bearings.

In making tests, it is absolutely necessary that a proper place be selected for the various instruments. Instruments should not be placed upon the floor for they are not only liable to be injured but in that position they are extremely hard to read.

Great care should be taken in connecting the instruments in various circuits. All leads and wires should be placed so that no one will trip on them and thus wrench the instruments or pull them down. Where it is necessary to place the instrument lead wires under foot, they should be protected by a box or board.

Instruments must be level. They must not be tilted backwards, forwards, or sideways. The time required to place instruments in a solid, level position is time well spent.

Stray Fields. Occasionally errors are introduced into meter readings, due to the proximity of stray fields set up by bus bars, feeders, transformers, motors, or masses of iron. These may so modify the strength of the field in which the movable coil swings that the indications of the instrument are entirely untrustworthy. Special care **must** be exercised when working where stray fields exist.

The presence of direct-current stray fields may be detected by reading the instrument and then immediately turning it through 180 degrees and reading it again, the circuit conditions being maintained as constant as possible. If the readings are the same, no stray-field error is present. If the readings are different, stray fields are present. In this case, the true value is the average of the two readings. Having determined the presence of stray fields, the instruments should be shifted to a new location where the readings will not be affected.

Under ordinary working conditions, stray fields are not likely to produce much alteration in the instruments, however, violent short-circuits may cause permanent changes in the strength of the magnets, thus causing large errors. If such an accident has happened with either alternating or direct currents, no reliance should be placed on the instrument readings until they have been tested and found to be correct. Direct-current stray fields of ordinary strength cause a percentage change throughout the scale in the indications of moving coil ammeters and voltmeters.

Stray fields due to heavy currents in the leads to the instruments themselves must not be neglected. The leads must be free from loops and coils and should run straight away from the instruments and as close together as possible. Do not set moving-coil instruments on plates of iron, steel, or "tin" which is tinned iron. In general, one cannot assume that stray fields are constant in either direction or magnitude.

Careful attention must be given to these points when deciding on the location and arrangement of apparatus for a test. In any case when results are questioned, if one cannot prove that there were no stray-field errors, the measurements will not be accepted as

correct. When shielded instruments are used, stray-field errors are practically eliminated.

Electrostatic Attraction. Glass and hard-rubber instrument covers sometimes give trouble due to electrostatic charges, tending to attract the needle and thus unbalancing the moving element. Instrument covers should not be rubbed immediately before a reading is taken as such an action may place a charge on the glass cover. Surface charges may be dissipated by breathing on the instrument. This trouble is most likely to be experienced in cold dry weather.

Protection Against Personal Injury. It would be impossible to list all the different things which might happen to those who handle electrical apparatus, therefore only a few very general but important suggestions are made.

In conducting an electrical test, careful planning and proper equipment are the greatest safeguards against injury. Connections should be made in a neat, workmanlike manner so that they may be easily traced when checking the set-up or changing connections. When temporary switches are used, they should be held securely in place so that they can be operated with one hand.

When the instruments and apparatus have been connected ready for test, it is recommended that a second party carefully check the set-up before final connections to the live circuit are made. This precaution will prevent accidents and save many instruments. To ask a person to check test connections is not to doubt one's own ability, but rather it is the precautionary measure of one who does not wish to make a mistake.

A very good habit to acquire is that of working on live circuits with one hand only. If the other hand gets in the way, put it behind your back. This habit will pay dividends often. If your one hand does come in contact with live parts of opposite polarity, a dangerous shock does not result as the current does not pass through the body.

It is particularly important that the floor upon which one stands while performing tests be well insulated. Be extremely careful of cement floors which often appear dry on the surface but will act as a ground to a person standing on them. When working on poorly insulated floors, a heavy piece of **dry** wood or a rubber mat should be used.

Ammeter. The ammeter is perhaps the most useful and important of portable electrical instruments. Practically all modern electrical equipment while marked in horsepower or watts bears in addition a current rating which **must** not be exceeded. As an illustration of this, let us consider a motor rated at 10 horsepower, 115 volts, the name plate specifying 75 amperes. If the line voltage drops to 100 volts and the motor is called upon to deliver 10 horsepower, the current will be increased to 86 amperes. Since the motor windings are only designed to carry 75 amperes, overheating and eventually burning out of the windings will result.

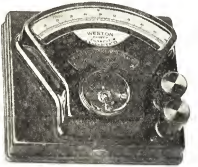


Fig. 1. Ammeter with Shunt Contained within the Instrument Case
Courtesy of Weston Electrical Instrument Corporation

Direct-current ammeters consist of a millivoltmeter, a shunt, and special leads for connecting the millivoltmeter to the shunt. Some ammeters, having a range of 25 amperes or less, are made self-contained, that is, the shunt and millivoltmeter are built into the same case. Fig. 1 shows an ammeter having the shunt contained within the instrument case. The method of connection into the circuit is shown in Fig. 2.

For general testing it is more economical to have one millivoltmeter with several shunts of various capacities so that one instrument may be used for several ranges. A very useful combination consists of a millivoltmeter having a scale marked as shown in Fig. 3, and three shunts of 3-, 15-, and 150-ampere capacity. The field of usefulness of the instrument for special testing can be further increased by the addition of a 1.5-ampere shunt for lower currents and 300-, 1500-, and 3000-ampere shunts for higher currents.

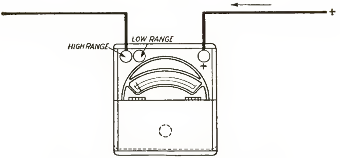


Fig. 2. Method of Connecting Ammeter into a Circuit

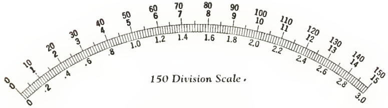


Fig. 3. 150 Division Scale

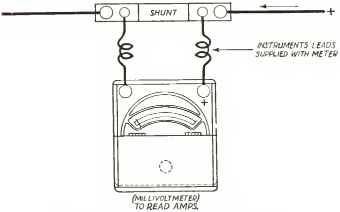


Fig. 4. Connections of an Ammeter with External Shunt

Fig. 4 shows the connections of an ammeter with external shunt. With instruments of this type, it is extremely important that the special leads provided by the manufacturer always be used to connect the millivoltmeter to the shunt being used and that all connections are tight. The special leads are actually a part of the millivoltmeter since it is calibrated in terms of the voltage drop at the shunt end of the leads. A change of lead resistance due to broken wires or the substitution of other leads not intended for this particular instrument may cause considerable error in the instrument readings. If leads become broken or lost, a new pair should be obtained from the maker of the instrument.

The ammeter is probably the most abused of all electrical instruments, many being burned out each year due to errors in connecting them in circuit. The most common error is to connect the shunt directly across the line as a voltmeter would be connected. As an illustration of what happens when this is done, let us calculate the current which might flow through an ammeter with a 15-ampere shunt.

Since the shunt is designed to produce a drop of .050 volt at 15 amperes, its resistance is

$$R=\frac{E}{I}=\frac{.050}{15}=.0033 \text{ ohm}$$

In the above formula, R means resistance, E means drop in volts produced by shunt, and I means number of amperes. In this formula, $R=\frac{E}{I}$, we can, therefore, use the real meaning of the letters and be able to solve and find the value of resistance. The drop in volts produced by the shunt is .050, so we substitute .050 for E. The number of amperes is 15, so we substitute 15 for I. The formula then becomes $R=\frac{.050}{15}$, as shown above. To solve $\frac{.050}{15}$, we divide .050 by the 15. The answer is .0033. Thus R (resistance) equals .0033 ohm.

If this shunt be connected directly across a 115-volt line of unlimited capacity, the current flowing through the shunt would be

$$I=\frac{E}{R}=\frac{115}{.0033}=34{,}848 \text{ amperes}$$

In this formula we see I, E, and R. From the preceding formula and explanation, we know that I = amperes. In this present formula I means current; but as the ampere is a measure of current, the I can be called either ampere or current. Also we know that E means volts and that R means resistance. In the preceding formula we were finding resistance, but now we want to find current. The formula for doing this is as shown above. Substitution is carried on as in the preceding formula. Thus $I = \frac{115}{.0033}$ and this means to divide 115 by .0033. The answer is 34,848 amperes.

This is a little more than 2000 times the current the shunt is intended to carry. The voltage applied to the millivoltmeter will also be 2000 times as great as that intended for it (normal maximum voltage 0.050 volt). Conditions, as described above, result in immediate destruction to both shunt and milliammeter and necessitate costly repairs.

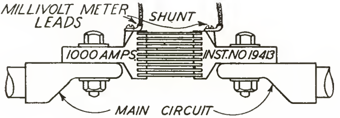


Fig. 5. Shunt Having Two Sets of Terminals

Of course, under usual test conditions, such a large current as that calculated above will not flow due to the limiting capacity of the generator and the resistance of the connections between the generator and the shunt. However, even a current of 150 amperes passing through a 15-ampere shunt for a very short time is sufficient to damage the instrument.

An ammeter must be connected in **series** with the line in which the current is to be measured. Also it is desirable to know that sufficient resistance is in series with the ammeter to limit the current to full-scale deflection of the ammeter before connecting it into the circuit.

Another cause of burned out millivoltmeters is due to not properly connecting the shunt into the circuit. Each shunt is provided with two sets of terminals as shown in Fig. 5. The outside heavily constructed terminals are for the line connections. The small inner terminals are for the millivoltmeter leads. For proper operation, connections must be made in this manner.

When ammeters are connected in series with a motor, it is desirable that a short-circuiting switch be provided to short out the ammeter during the current inrush caused when the motor is started. This is done by connecting a single-pole single-throw knife switch across the heavy current terminals of the ammeter shunt, or, in the case of a self-contained ammeter, directly across the ammeter terminals. In any case where it is desired to leave an ammeter connected into a circuit for a considerable length of time, it is good practice to provide a short-circuiting switch and keep the ammeter short-circuited except when readings are to be taken.

Use of the Voltmeter. A voltmeter, Fig. 6, is used to measure voltage or potential difference. It is connected across the line between the two wires of the circuit, the potential difference of which it is desired to measure. Voltmeters are of relatively high resistance. A standard instrument having a full-scale deflection (maximum scale marking) of 15 volts has a resistance of approximately 1500 ohms. An instrument suitable for a maximum scale reading of 150 volts has a resistance of approximately 15,000 ohms. Fig. 6 shows two types of voltmeters.

Voltage, potential difference or electromotive force, is indicated by the voltmeter indirectly. The voltmeter is actuated by the current passing through it due to the voltage applied. Instead, however, of marking the value of the current in amperes on the scale, it is customary to mark the value of the voltage applied at its terminals, which results in a given deflection. By Ohm's Law the current through the instrument is proportional to the voltage applied, so that the instrument scale can be graduated in volts. The range, or full-scale reading, of a voltmeter may be increased by adding resistance in series with it. These series resistances are usually designed so that the voltage required to give full-scale deflection is two, three, or four times the marking of the instrument scale. These series resistances are known as **multipliers.**

Fig. 7 shows a 150-volt voltmeter connected to measure a line voltage of 115 volts. Fig. 8 shows a 150-volt voltmeter with a multiplier having a multiplying factor of 2 connected to measure a line voltage of 230 volts.

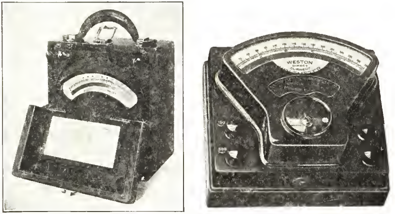


Fig. 6. Two Types of Voltmeters
Courtesy of Weston Electrical Instrument Corporation

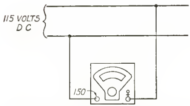


Fig. 7. 150-Volt Voltmeter Connected to Measure a Line Voltage of 115 Volts

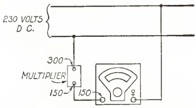


Fig. 8. 150-Volt Voltmeter with Multiplier

Units of Electrical Measurement. Although the exact nature of electricity is not known, experience has taught us that the flow of electricity through a circuit resembles in many ways the flow of water through pipes. It acts as an incompressible liquid would, the quantity flowing (current) depending on the size of the conductor (resistance) and the pressure (voltage).

Current. The unit of electric current is the ampere and represents the rate of flow of electricity. It corresponds, in hydraulics, to the rate of flow of water, expressed as cubic feet per second or gallons per minute. Current is measured in amperes by an ammeter placed in series with the circuit under test.

Difference of Potential or Electromotive Force. Difference of potential, voltage, or electromotive force, tends to cause a flow of electricity. The unit of potential difference is the volt. This may be compared to things in everyday life which are more commonly known. The flow of water through a pipe is caused by the difference of pressure at the two ends. The pressure in a steam boiler causes steam to flow through pipes and drive engines. In other words, the volt may be compared to pressure. Voltage is measured by means of a voltmeter just as a gage measures pressure in a steam boiler.

Resistance. Resistance is defined as that property of an electric conductor by which it opposes the passage of an electric current. It is due to this resistance that heat is generated when current flows through a conductor. The unit of resistance is the ohm.

Resistance in the electric circuit may be likened in its effect to friction in mechanics. For example, if a street car is running at a uniform speed on a level track, friction tends to prevent the moving of the car. The power which is used in moving the car is converted by friction into heat. A heavy block of wood requires considerable energy to drag it along on the ground. If the same block of wood is floating in water, very little energy is required to move it. The ground surface offers high resistance to the movement of the block. The water offers low resistance.

The current flowing through an electric circuit depends not only upon the voltage applied to the circuit but upon the resistance of the circuit as well. For example, if a wire be connected across the terminals of a battery, a current will flow through this wire. If a poor contact be made at a battery terminal or at some other point in the circuit, the current will drop in value, even with the same voltage acting. Also considerable heat will be lost at the point of poor contact. This property of tending to prevent the flow of current and at the same time causing heat loss is called resistance

All substances have resistance, but the resistance of some substances is many times greater than that of others. This leads to the classification of substances as either conductors or insulators. Even silver, one of the best conductors, has appreciable resistance; and glass or porcelain, among the best known insulators, will allow a certain amount of current to pass and therefore are not perfect insulators. The best conductors are the metals—silver coming first and copper second. Oils, glass, silk, paper, cotton, fiber, ebonite, paraffin, wood, and the like may be considered as non-conductors or good insulators when free from moisture.

Metals offer comparatively little resistance to the passage of current and, for practical purposes, are the best conductors. Silver offers the least resistance of any metal but the metals most used commercially for the transmission of electrical energy are copper, aluminum, and iron or steel. The resistance of a wire or conductor varies with its material, its length and thickness. The longer and thinner a wire, the greater its resistance.

Resistance may be determined by measurement of current and voltage and a simple calculation based upon Ohm's Law, as has been shown on page 6.

Electrical Power. The unit of electrical power is the watt. It may be defined as the power developed by a current of one ampere flowing due to a potential difference of one volt. Therefore, for direct current, watts are equal to the product of volts and amperes.

Ohm's Law. Ohm's Law defines the properties of an electrical circuit in terms of current, voltage, and resistance. Knowing any two of these factors, the third may be calculated by simple multiplication or division.

One statement of Ohm's Law is: *The current in a circuit in amperes is equal to the voltage impressed on the circuit in volts divided by the resistance of the circuit in ohms.*

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \qquad \text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

A second statement of Ohm's Law is: *The voltage between two points in a circuit equals the current in amperes multiplied by the resistance in ohms.*

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$
$$\text{Volts} = \text{Amperes} \times \text{Ohms}$$

A third statement of Ohm's Law is: *The resistance in ohms of a circuit equals the voltage applied divided by the current in amperes.*

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \qquad \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

Simple Method of Using Ohm's Law. Ohm's Law is the basis of nearly all electrical calculations. As such, it is essential that its various forms should be readily available. A simple method of memorizing Ohm's Law is embodied in Figs. 9, 10, 11, and 12.

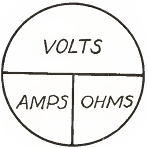


Fig. 9.

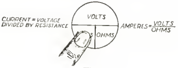


Fig. 10.

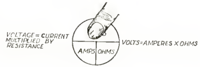


Fig. 11.

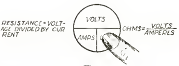


Fig. 12.

Method for Memorizing Ohm's Law

Fig. 9 is a diagram representing the various relationships of Ohm's Law which may be quickly constructed from memory when a problem is to be solved. Suppose that we wished to determine the current flow in a circuit. Remember that when we speak of measuring a current we think in terms of amperes. Now, look at Fig. 9 and note the positions of the three terms used in Ohm's Law. To find the amperes, which will give us the current flow, we place one finger over the word amperes, as shown in Fig. 10. Thus we see that the two terms needed are the ones visible, or volts and ohms. Ohms is the unit of electrical resistance, so knowing the resistance and voltage, we can divide the voltage by the resistance, in ohms,

and get the current, or amperes, as a result. In all cases where we wish to calculate one term, we must know the other two.

Illustrative Example. In a circuit the voltage is 112 and the resistance is 4 ohms. Determine the current flow.

Knowing that amperes is a measure of current, we can find the amperes and thus solve the problem. Refer to Fig. 9 and put your finger over the word **amperes.** This leaves **volts** and **ohms** visible, as shown in Fig. 10. At the right of Fig. 10 is the formula $\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$. We know the voltage and resistance in ohms so we can substitute these real values in the formula and have, $\text{Amperes} = \frac{112}{4} = 28$. To the left of Fig. 10 the explanation says to divide voltage by resistance to find current. This would give us exactly the same results as the formula we used, so it can be seen that the statement on the left of Fig. 10 and the formula on the right mean the same.

Notice that Fig. 10 shows not only the terms necessary to find amperes, but that it also shows them in their correct mathematical position. Volts is placed over ohms just as in the formula. In Fig. 11, the two terms are side by side, indicating multiplication, and in Fig. 12 one over the other indicating division.

Measurement of Resistance. One of the more common uses of direct-current indicating instruments is for the measurement of resistance. This is particularly true of maintenance and repair work where resistance measurements are essential in the location of faults and the making of proper replacements. As the variety of applications is great, we shall consider only those illustrating the general problems discussed.

Voltmeter-Ammeter Method of Measuring Resistance. The simplest and most obvious method of determining electrical resistance is by the application of Ohm's Law. *The voltage drop between the terminals of the resistance and the current flowing through the resistance* is measured directly by suitable voltmeters and ammeters connected as shown in Fig. 13.

Referring to our simple representation of Ohm's Law

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \qquad \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

Let us assume we wish to know the resistance of the electric flatiron shown in Fig. 13. Voltage is supplied from a 115-volt direct-current circuit. The test circuit consists of a switch, a fuse, a 100-ohm rheostat, the iron to be tested for resistance with the 150 voltmeter connected across its terminals, and the 3-ampere ammeter shunt completing the circuit to the other line.

The switch is placed in the circuit that we may make and break the circuit as we please. The fuse protects us as well as the apparatus under test from accidental short circuit. The rheostat is to regulate the current so that a suitable reading may be obtained.

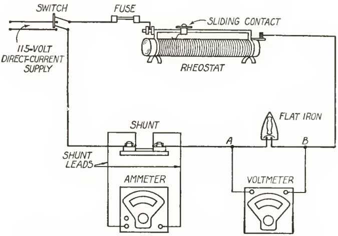


Fig. 13. Voltmeter and Ammeter Connected so as to Measure Resistance

Before closing the switch, the rheostat slider is pushed as far to the left as possible, thus putting all the resistance in the circuit. We also open the voltmeter circuit by either taking off one of the leads or releasing the voltmeter key. One of the ammeter shunt leads is also removed from the ammeter so that both of the instruments are on open circuit. A fuse of about three amperes capacity should be used. With the meters disconnected and the fuse in the circuit, we are ready for a tryout. The switch is closed and the circuit is watched closely for signs of trouble. If nothing happens, we are ready to connect in the instruments. First, we will connect

the ammeter shunt lead previously removed and again close the switch. This time the ammeter must be closely watched. If the current is great enough to force the needle to the extreme right, open the switch immediately to avoid burning out the ammeter. The needle should indicate only a very small current flowing. We

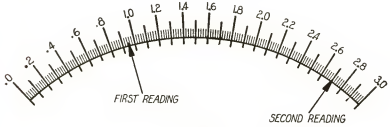


Fig. 14. Current Readings Shown on Ammeter

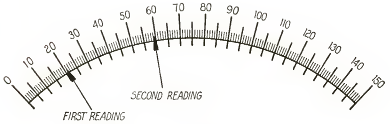


Fig. 15. Voltage Readings Shown on Voltmeter

are now ready to connect the voltmeter, which should also show a low reading. The meters will indicate about as shown for the first reading in Figs. 14 and 15, the ammeter 0.95 ampere and the voltmeter 21 volts. Knowing the current and voltage, the resistance may be calculated by Ohm's Law.

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{21}{0.95} = 22.1 \text{ ohms}$$

We may take another measurement of the flatiron resistance by increasing the current to say 2.7 amperes. This is done by

cutting out part of the rheostat resistance. The voltmeter now reads 59.5 volts. See second reading indicated in Figs. 14 and 15. These values we use as before.

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{59.5}{2.7} = 22 \text{ ohms}$$

These two calculations resulting in so nearly the same value indicate that the instruments have been very carefully and accurately read. It is well, where possible and when accurate measurement is desired, to take readings at several different current values.

The procedure outlined in the foregoing is typical of the method employed to measure resistances of unknown values. The resistance of the flatiron under test might have been determined by connecting the iron directly across the 115-volt supply with the ammeter in series and the voltmeter in parallel. However, should the heating element be short-circuited, the line fuse would be blown and possibly damage done to the instruments.

Error Due to Current Taken by Voltmeter. The above calculation is approximate, due to the fact that all the current measured by the ammeter does not flow through the flatiron heater element from point A to point B of Fig. 13. A small amount of current is taken by the voltmeter and thus does not pass through the iron. The voltmeter indicates the voltage drop from point A to point B. In order to calculate with accuracy the resistance, it is necessary to know the exact amount of current flowing through the heater element.

Now the ammeter indicates the total amount of current flowing in the circuit. This same current flows from A to B, Fig. 13, part going through the flatiron heater element and part through the voltmeter. Therefore the ammeter indicates the sum of the currents flowing through the heater element and through the voltmeter. The true current flowing through the heater element is then the total indicated current less the current taken by the voltmeter. Since the resistance of the voltmeter is usually known, being marked in the cover of the instrument or on the scale of the meter, the current taken by the voltmeter may easily be calculated by Ohm's Law. (See Fig. 10, page 12.)

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Let us assume in this case that we are using a voltmeter whose resistance, when connected to indicate on the 150-volt scale, is 15,000 ohms (100 ohms per volt). Taking the first measurement above when the current was 0.95 ampere and the drop 21 volts, since the voltage drop at the terminals of the voltmeter is also 21 volts, then current through the voltmeter is, by Ohm's Law,

$$\text{Current} = \frac{\text{Volt}}{\text{Resistance}} = \frac{21}{15000} = .0014 \text{ ampere}$$

The actual current passing through the heating element is therefore

$$0.95 - .0014 = .9486 \text{ ampere}$$

Now refer to Fig. 14, showing the ammeter deflection for the first reading, and mark off the position corresponding to .9486 ampere. You will find this position so near to .95 ampere that the difference in deflection cannot be detected. In this case the correction for current taken by the voltmeter is too small to be accounted for.

Let us make the same check for the second set of readings taken with the circuit, as shown in Fig. 13, where the current was 2.7 amperes and 59.5 volts.

$$\text{Voltmeter current} = \frac{\text{Volts}}{\text{Resistance}} = \frac{59.5}{15000} = .004 \text{ ampere}$$

The actual current passing through the iron is

$$2.7 - .004 = 2.696 \text{ amperes}$$

This value also is so near the actual reading that it is useless to apply the correction.

In the case just discussed, a correction for the current taken by the voltmeter is unnecessary. However, this is not always true, for sometimes a very great error may be introduced into the calculations if the current taken by the voltmeter is neglected. This is particularly true when measuring high resistances. For ordinary calculations if the current indicated by the ammeter is one hundred times that taken by the voltmeter, a correction is unnecessary.

A quick method of checking whether or not to correct for the voltmeter current is to energize the circuit and then make and break

the voltmeter circuit. If the ammeter indicates a greater reading with the voltmeter connected in the circuit than when it is disconnected, a correction should be made by the method described above.

Determination of Wattage. As an additional check on the iron, one may calculate its wattage at normal voltage. *Wattage in a direct-current circuit is equal to the current passing through the circuit multiplied by the voltage drop across the circuit.* If the line voltage applied to the iron is to be 115 volts and the resistance of the heating element 22 ohms, we may calculate the current through the iron by Ohm's Law.

$$\text{Current} = \frac{\text{Volts}}{\text{Resistance}} = \frac{115}{22} = 5.23 \text{ amperes}$$

The wattage of the iron is then

$$\text{Current} \times \text{Voltage} = 5.23 \times 115 = 600 \text{ watts}$$

Resistances in Series and Parallel. As an illustration of the effect of connecting resistances in series and in parallel, let us consider two 115-volt 500-watt space heaters, similar to those used for electrically heating cars and small ovens. It will first be necessary to measure the resistance of each space heater separately. Fig. 16 shows the circuit which consists of a switch, a 5-ampere fuse, a rheostat, a 150-volt voltmeter, an ammeter with a 5-ampere shunt, and the space heater, the resistance of which is to be measured. In order that the space heaters do not become too hot to handle, we shall apply something less than half the usual amount of current. This is done by cutting all of the resistance in the rheostat into the circuit and then closing the switch. With all the rheostat resistance in the circuit, the meter readings are low; and in order to increase the current, we cut out some of the rheostat resistance. Let us assume that the ammeter and voltmeter readings are as shown in Fig. 17, Trial 1. The ammeter indicates 2.07 amperes and the voltmeter 53.5 volts. By Ohm's Law, we may now calculate the resistance of the space heater.

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{53.5}{2.07} = 25.8 \text{ ohms}$$

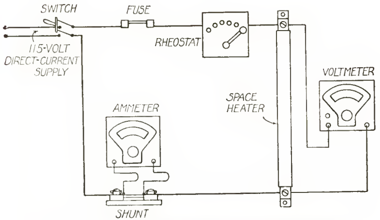


Fig. 16. Circuit Connections for Measuring Resistance of an Electric Heater

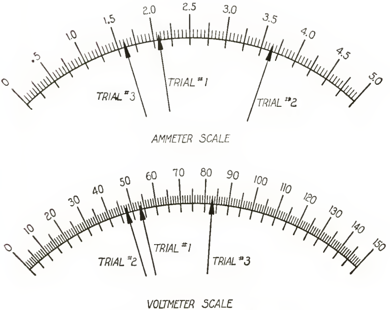


Fig. 17. Ammeter and Voltmeter Readings

In like manner, the second space heater is tested and its resistance is found to be the same as the first.

With the current and voltage applied to our space heater, as noted above, the wattage dissipated is

$$\text{Wattage} = \text{Volts} \times \text{Amperes} = 53.5 \times 2.07 = 110.7 \text{ watts}$$

If 115 volts were applied to the space heater, the current through it would be by Ohm's Law

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}} = \frac{115}{25.8} = 4.46 \text{ amperes}$$

The wattage dissipated by the space heater would be

$$\text{Wattage} = \text{Volts} \times \text{Amperes} = 115 \times 4.46 = 512.9 \text{ watts}$$

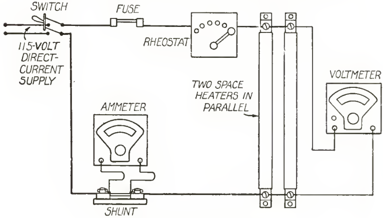


Fig. 18. Space Heaters Connected in Parallel

Resistances in Parallel. With the space heaters connected in parallel, as shown in Fig. 18, we may calculate the resistance from the individual resistance values or we may measure it as before. Let us do both.

The total resistance of two resistances connected in parallel is equal to the resistance value of one multiplied by the resistance value of the other and then divided by the sum of the two resistance values. In this case the parallel resistance is

$$\text{Resistance} = \frac{25.8 \times 25.8}{25.8 + 25.8} = 12.9 \text{ ohms}$$

Now let us measure the resistance of the two space heaters connected in parallel. The readings are as shown for Trial 2, Fig. 17. The ammeter shows 3.65 amperes and the voltmeter 47.5 volts. By Ohm's Law, we have

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{47.5}{3.65} = 13.0 \text{ ohms}$$

With 47.5 volts applied, the watts dissipated in the two space heaters in parallel is

$$\text{Wattage} = \text{Volts} \times \text{Amperes} = 47.5 \times 3.65 = 173.3 \text{ watts}$$

If 115 volts were applied to the two heaters in parallel, the current through the circuit would be

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}} = \frac{115}{13} = 8.85 \text{ amperes}$$

The wattage dissipated at 115 volts would be

$$\text{Wattage} = \text{Volts} \times \text{Amperes} = 115 \times 8.85 = 1017.7 \text{ watts}$$

which is approximately twice the wattage of one space heater alone.

Resistances in Series. Next consider the two space heaters connected in series as shown in Fig. 19. The resistance of a series combination equals the sum of the resistance of the separate parts. Since we know that each space heater has a resistance of 25.8 ohms, the total resistance when the two are connected in series is

$$25.8 + 25.8 = 51.6 \text{ ohms}$$

When measured electrically, the instruments indicate readings as shown for Trial 3, Fig. 17, ammeter 1.60 amperes and voltmeter 83.0 volts. Calculating by Ohm's Law, we have

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{83.0}{1.60} = 51.87 \text{ ohms}$$

The wattage for the two space heaters in series, when 83.0 volts is applied, is

$$\text{Wattage} = \text{Volts} \times \text{Amperes} = 83.0 \times 1.60 = 132.8 \text{ watts}$$

If 115 volts were applied to the two heaters in series, the current through them will be

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}} = \frac{115}{51.87} = 2.22 \text{ amperes}$$

The total wattage is

$$\text{Wattage} = \text{Volts} \times \text{Amperes} = 115 \times 2.22 = 255.3 \text{ watts}$$

This also checks with the value obtained for a single space heater. With the two heaters in series, the resistance is doubled and the current reduced to one-half, therefore, the total wattage is one-half that of a single heater connected directly across 115 volts.

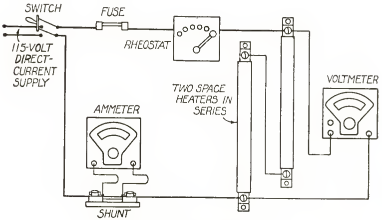


Fig. 19. Space Heaters Connected in Series

Accuracy of Readings. While none of these values exactly correspond, they do check quite closely. Better accuracy could be obtained by taking a large number of readings for each condition and averaging the values.

The current taken by the voltmeter in each of the above cases is so small that it does not materially affect the calculations.

High Resistances. So far it has been unnecessary to apply the correction for the current taken by the voltmeter. Let us now measure the resistance of an electrical contactor operating coil.

The contactor, shown in Fig. 20, has a coil designed for 230-volt direct current. For this measurement we shall need a low reading ammeter having a full-scale deflection of say 0.300 ampere. A meter of this type is called a milliammeter and has a range of 300 milliamperes. (1000 milliamperes equals 1 ampere. 300 milliamperes equals 0.3 or $\frac{300}{1000}$ ampere.) In order to avoid confusion it is best to record all readings taken with a milliammeter in fractions of an ampere instead of in milliamperes.

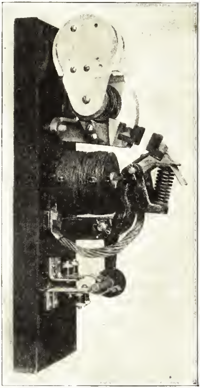


Fig. 20. A Contactor
Courtesy of Cutler-Hammer, Inc.

If the contactor coil in Fig. 20 is substituted for the space heater in Fig. 16 and the switch closed, the deflection on the 5-ampere ammeter will be very small. When all the resistance is cut out of the rheostat, the ammeter will indicate about 0.1 ampere or about 2 small divisions above zero. This indicates that the 300-milliampere meter may be substituted for the 5-ampere shunt and meter. Now with all of the rheostat resistance cut out, we find the deflection of the voltmeter to be 112 volts and the milliammeter indicates 0.107 or $\frac{107}{1000}$ ampere.

The resistance by Ohm's Law, using the values as read, is

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{112}{.107} = 1047 \text{ ohms}$$

The voltmeter resistance for this 150-volt scale is 15,000 ohms, so the current passing through the voltmeter when it indicates 112 volts is

$$\text{Current} = \frac{\text{Volts}}{\text{Resistance}} = \frac{112}{15000} = .0075 \text{ ampere}$$

The actual current flowing through the coil under test is then $.107 - .0075$ or .0995 ampere.

The true coil resistance is

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}} = \frac{112}{.0995} = 1126 \text{ ohms}$$

Neglecting to correct the instrument readings for the current taken by the voltmeter in this case amounts to an error of 79 ohms, or approximately 7 per cent.

Insulation Resistance Measurements. To measure very high resistances, the volt-ammeter method is not practical due to the extremely sensitive milliammeter which would be required. The circuit used to measure resistances above several thousand ohms is shown in Fig. 21. This is known as the series voltmeter method. It makes use of a voltmeter of known resistance as a milliammeter. With the single-pole double-throw switch closed to position A, the voltmeter indicates the line voltage. When the switch is closed to position B, the voltmeter indicates the voltage drop across the voltmeter terminals caused by the current flowing through the insulation being tested. Since the resistance of the voltmeter is known, the current passing through the voltmeter may be calculated by Ohm's Law.

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}}$$

In a series circuit, the current passing through the various parts is the same and is determined by the voltage applied to the circuit and the total resistance of the circuit. Also the total voltage drop of a series circuit is equal to the sum of the voltage drops of its various parts. In Fig. 21, the total voltage drop, as measured with the switch in position A, is equal to the voltage drop across the motor insulation plus the voltage drop across the voltmeter when the switch is in position B. The voltage drop across the motor insulation, the resistance of which we wish to obtain. is therefore equal to the voltmeter reading with the switch in position A minus the voltmeter reading with the switch in position B.

Knowing the current passing through the insulation under test and the voltage drop across it, the insulation resistance is calculated by Ohm's Law

$$\text{Resistance} = \frac{\text{Volts}}{\text{Amperes}}$$

For general use these values are combined in our general equation as follows:

$$\text{Insulation Resistance} = \frac{\text{Line Voltage} - \text{Series Voltage}}{\text{Series Voltage}} \times \text{Voltmeter Resistance}$$

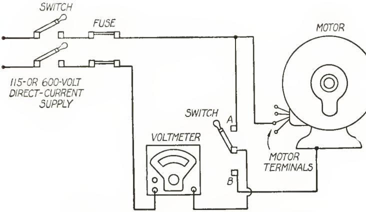


Fig. 21. Circuit Connections for Testing Motor Insulation

Test of Insulation Resistance. As an illustration of the method of calculating insulation resistance, let us consider tests made on a motor which has been water-soaked. If this motor was operated with moisture in the insulation, it would in all probability burn out.

The first step is to measure the insulation resistance of the motor just as it is. Carefully wipe all moisture off the frame, commutator, and brush rigging. Insulate the frame of the motor from ground by placing it on dry wood and arrange the circuit as shown in Fig. 21.

We will assume that the voltage supply is 115 volts and that the voltmeter resistance for the 150-volt range is 15,000 ohms. With the switch in position A, the voltmeter indicates 115 volts. When

the switch is in position B, the voltmeter indicates 110 volts. By the formula given above

$$\text{Insulation Resistance} = \frac{115-110}{110} \times 15000 = 681.8 \text{ ohms}$$

This value of insulation resistance indicates that the insulation is badly water-soaked, so the motor must be dried by baking. After baking, another insulation test is made and the following reading recorded. Line voltage, switch in position A, 115 volts. Series voltage, switch in position B, 1.5 volts.

$$\text{Insulation Resistance} = \frac{115-1.5}{1.5} \times 15000 = 1{,}135{,}000 \text{ ohms}$$

This indicates that the insulation is in very good condition.

A VOLTMETER, AMMETER, AND OHMMETER ARE COMBINED IN ONE PORTABLE INSTRUMENT

Pushing the DC–AC switch to left will read direct-current volts, amperes or milliamperes on the lower scale and ohms or megohms on the top scale as selected by selector switch. Alternating-current voltages are read on the center scale.

Courtesy of Triplett Electrical Instrument Co., Bluffton, Ohio

REVIEW QUESTIONS

1. What is one of the most common causes of burned-out ammeters? What occurs?

2. Describe briefly the voltmeter-ammeter method of measuring resistance.

3. In a low-resistance circuit, is the error due to the current taken by the voltmeter a major factor? Why?

4. Describe one way you could check to see if the error due to the voltmeter were important enough to consider.

5. What is the rule for calculating the value of two resistances in *parallel?*

6. What would be the value of two 100-ohm resistors connected in *series?* In *parallel?*

7. Compute the combined resistance of a 75-ohm and a 56-ohm resistor connected in *parallel.*

8. If a 1,000-ohm resistor is connected in *parallel* with a 1-ohm resistor, what is the combined resistance? What conclusion may you draw from this problem?

9. If a space heater has a resistance of 20 ohms, what is the wattage dissipation when it is connected to a 120-volt line? To a 240-volt line? What conclusion can you draw regarding the value of voltage applied to a resistor and regarding the wattage dissipated? Did the value of current drawn by the resistor change?

10. If two 20-ohm space heaters are connected in *parallel* across a 120-volt line, what is the total wattage dissipation? If they are connected in *series?*

APPLICATIONS TO INDUSTRY

1. If a motor is rated at 13 amperes, why does a 15-ampere ammeter connected to it kick off scale each time the motor is turned on?

2. To avoid damaging the instrument in question 1, what should you do? Draw a simple sketch.

3. What are *stray fields* and how do they affect the readings of meters?

4. Why is it important, when working on high-tension circuits, to keep one hand behind your back or in a pocket?

5. Why should you stand on a piece of dry wood or a rubber mat when working on electrical circuits?

6. If a fuse is inserted in a circuit to protect a 15-ampere meter, what should be the maximum size of the fuse?

7. As you are using a 100-ohm-per-volt voltmeter on the 150-volt range across a load resistance of approximately 15,000 ohms, you notice that the reading of the ammeter in series with the load almost doubles when you connect the voltmeter. To what do you attribute this?

8. Draw a simple circuit showing how you would connect a voltmeter to determine insulation resistance of a motor or transformer.

9. What is the formula for finding insulation resistance by the method in question 8?

10. If a certain ammeter is designed to produce a drop of .064 volts, at 16 amperes, calculate the resistance of the meter in ohms.

WESTON MODEL 329 POLYPHASE WATTMETER WITH VOLTAGE TERMINALS FOR 150 AND 300 VOLTS

Maximum current up to 20 amperes with links connected in parallel as shown in illustration.

Courtesy of Weston Electrical Instrument Corp.

ELECTRICAL POWER MEASUREMENTS

Work and Power. The words **work** and **power** are often confused or interchanged in common use. The proper use of the term **work** means the overcoming of resistance. **Power** means the speed or rate of doing work.

$$\text{Work} = \text{Force} \times \text{Distance}$$

When a force acts upon a body, the product of the force multiplied by the distance through which it acts in the direction of the force is called the work performed by the force. Thus, when a force applied to a heavy body raises it a vertical distance, work is performed by the force. The amount of work is the product of the force and the distance of ascent. In other words, **work** is the result obtained by multiplying the force it takes to pull a bucket of water upward by the distance the bucket was raised.

Force is generally measured in pounds and distance is in feet, so when the two are multiplied together, as explained above, the result is foot pounds. Therefore, the term **foot pound** is the measure of work.

Fig. 1 shows a man carrying a bucket of water weighing 20 pounds up a flight of stairs to a platform 10 feet high. The force required to lift the bucket of water is 20 pounds, and the vertical distance it has been raised is 10 feet. The force required to lift a load or weight of any kind is always equal to the load. If an object weighs 20 pounds, then 20 pounds of force is required to lift it. The quantity of **work** the man has done is the product of the force and the distance upward, or 20 pounds multiplied by 10 feet, which equals 200 foot pounds. In formula form this is written as follows:

$$\text{Work} = 20 \times 10 = 200 \text{ foot pounds}$$

Fig. 2 represents a man raising a bucket of water weighing 20 pounds, to a platform 10 feet above the level upon which he is standing, by means of a rope and pulley. Here again the force is 20 pounds and the vertical distance is 10 feet. The **work** performed

is still force times distance, or $20 \times 10 = 200$ foot pounds. The 20 represents the force and the 10 the distance, as in above.

Suppose, instead of lifting the water by manual effort, it is forced up to the bucket by a pump driven by a motor, as shown in Fig. 3. In order to fill the bucket, which is placed upon the platform 10 feet above the level of the water tank, 20 pounds of water are required. Therefore, the motor must do 200 foot pounds of **work.** Here the motor does the work done by the man in Figs. 1 and 2. When a horizontal force moves a body horizontally, the **work** is the product of the force and the horizontal distance. As

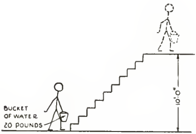


Fig. 1. Man Carrying a Bucket of Water Up a Vertical Distance

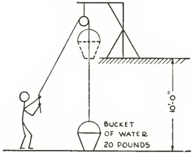


Fig. 2. Raising a Bucket of Water By Means of a Rope and Pulley

an example of this, take the ordinary street car in which motors are used to push the car along the street.

Fig. 4 shows a man pushing a cart. To keep the cart moving at a constant speed, it is necessary that the man apply a force of 20 pounds to overcome the friction or resistance to motion. Therefore, when he has pushed the cart 100 feet, he has performed an amount of work equal to force times distance, or

$$20 \times 100 = 2000 \text{ foot pounds}$$

In any of the above cases no mention of time has been made. The amount of **work** done is the same whether the task has been performed in one minute or one hour.

Power. In the formula for calculating **power,** it is necessary to divide the force times the distance (in other words, the **work**) by the time taken to do the work.

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{Time}} = \frac{\text{Work}}{\text{Time}}$$

Power means the speed or rate of doing work. The faster **work** is done, the greater the **power** required to do it. Fig. 3 shows a motor-driven pump raising water from a tank to a platform 10 feet above it. To deliver 20 pounds of water, it will take 200 foot pounds of work. In order to deliver this water at the rate of 20 pounds per second to a height of 10 feet, the power required is $\frac{20 \times 10}{1} = 200$ foot pounds per second, or $200 \times 60 = 12{,}000$ foot pounds per minute. First, we found the **power** required per second to lift 20 pounds of water in a second by dividing the **work** by **one second.** Then we found the foot pounds per minute by multiply-

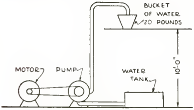


Fig. 3. Pumping Water By Means of a Motor Driven Pump

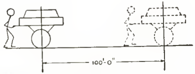


Fig. 4. Man Pushing a Cart in Which Resistance to Motion Is Twenty Pounds

ing 200 by the number of seconds in a minute. Suppose the man shown in Fig. 4 pushes the cart 100 feet in six seconds. The power required is **work** done divided by the time, or $\frac{20 \times 100}{6} = 333\frac{1}{3}$ foot pounds per second.

Study the above explanations very carefully until you are sure you understand them and will remember them.

Horsepower. The earliest use of steam engines was to pump water from mines. This work had previously been done by horses, consequently, the power of the various engines was estimated as equal to that of so many horses. Finally, James Watt carried out some experiments to determine how many foot pounds of work a horse could do in one minute. He found that a strong dray horse working for a short time could do work at the rate of 33,000 foot pounds per minute. This rate is therefore called horsepower. To

determine the horsepower of a machine, compute the number of foot pounds of work per minute and then divide by 33,000.

$$\text{Horsepower} = \frac{\text{foot pounds per minute}}{33{,}000}$$

Referring to Fig. 3, the horsepower required to raise 20 pounds of water 10 feet in one second is

Horsepower =

$$\overset{\text{(A)}}{\frac{\text{pounds per minute}\times\text{height}}{33{,}000}} = \overset{\text{(B)}}{\frac{\text{foot pounds per minute}}{33{,}000}} = \overset{\text{(C)}}{\frac{12{,}000}{33{,}000}} = 0.36$$

The first part (A) of this horsepower formula refers to the explanation for finding **power.** If 20 pounds of water must be lifted per second, then in 60 seconds (one minute) $20\times60=1200$ pounds of water would be lifted. We must always base our calculations on minutes, because the horsepower formula is based on minutes. Now if we multiply 1200 by 10 (the distance), we get 12,000 foot pounds, which is the power. Thus the formula at (A) could be written

$$\text{Horsepower} = \frac{12{,}000}{33{,}000}$$

The second part (B) of the horsepower formula means the same as the part at (A). The only difference is in the wording, because pounds per minute times height gives foot pounds per minute. So (B) could be written

$$\text{Horsepower} = \frac{12{,}000}{33{,}000}$$

In the third part (C) of the horsepower formula, we have used the numerical value of pounds per minute times height and foot pounds per minute. Then 12,000 is divided by 33,000 and the answer is as shown. These three steps show how the horsepower formula is developed and should be very carefully studied.

The horsepower required to push the cart, Fig. 4, a distance of 100 feet in 6 seconds, that is, to do 20,000 (see explanation on page 3) foot pounds work per minute, is

$$\text{Horsepower} = \frac{\text{foot pounds per minute}}{33{,}000} = \frac{20{,}000}{33{,}000} = 0.6$$

Electric Power. To measure waterpower, we must know the quantity of water flowing by a given point per minute and the head (which means height) to which it is raised.

$$\text{Waterpower} = \text{quantity of water per minute} \times \text{head}$$

$$\text{Horsepower} = \frac{\text{pounds per minute} \times \text{head}}{33{,}000}$$

To measure electric power, we must multiply the quantity of electricity flowing per second, that is, the current in amperes, by the voltage.

$$\text{Electric power} = \text{Amperes} \times \text{Volts}$$

In the problem illustrated by Fig. 3, it was stated that 20 pounds of water was being delivered to the platform in one second. Thus we speak of the water as flowing at the rate of 20 pounds per second. In much the same way we speak of electricity as flowing along a wire at the rate of so many **coulombs** per second. The coulomb is the unit of quantity of electricity, just as the gallon is the unit of quantity of water. We have to consider the rate of flow of electricity so often that we have a special name for the unit of rate of flow (one coulomb per second). We call it an **ampere.** Thus 5 amperes means 5 coulombs per second.

The **watt** is the unit of electric power and may be defined as the power required to keep a current of one ampere flowing under a drop or head of one volt. For example, if a lamp draws 0.5 amperes from a 110-volt circuit, it is using power at the rate of $0.5 \times 110 = 55$ watts. Since the watt is a very small unit of power, we commonly use the kilowatt (Kw.), which is 1000 watts.

$$\text{Kilowatt} = \frac{\text{Amperes} \times \text{Volts}}{1000}$$

Inasmuch as mechanical power is reckoned in horsepower, it will be convenient to know the relation of the unit of mechanical power to the unit of electrical power. Experiment shows that

$$1 \text{ horsepower} = 746 \text{ watts}$$
$$1 \text{ kilowatt} = 1.34 \text{ horsepower}$$

DIRECT-CURRENT POWER MEASUREMENTS

Volt-Ammeter Method. In direct-current circuits, power is equal to the product of the volts applied to the load times the current in amperes passing through the load.

$$\text{Power} = \text{Volts} \times \text{Amperes}$$

It is therefore the usual practice to measure direct-current power by means of a voltmeter and an ammeter, it only being necessary

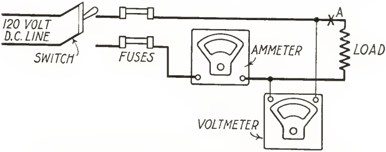


Fig. 5. The Best Method of Connecting Meters When Current Is Large

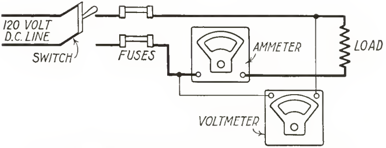


Fig. 6. The Best Method of Connecting Meters When Current Is Very Small

to multiply the volts by the amperes to obtain the power in watts. Particular care must be taken that they are the true values as stated above, namely, the volts applied to the load and the current in amperes passing through the load. To obtain these values certain precautions are necessary. Should the meters be connected as shown in Fig. 5 or in Fig. 6? The voltmeter, connected as shown in Fig. 5, measures the true volts applied to the load but the ammeter reads the sum of the current taken by the load and that pass-

ing through the voltmeter. When connections are made, as shown in Fig. 6, the ammeter indicates the exact amount of current passing through the load but the voltmeter indicates the sum of the voltage drop across the lamp and the voltage drop across the ammeter.

Power calculated from the indications obtained with connections as in Fig. 5 would indicate the watts delivered to the load plus the watts dissipated in the voltmeter. If the voltmeter resistance is known, its wattage may be calculated by dividing the voltage squared (multiplied by itself) by the resistance.

$$\text{Voltmeter Watts} = \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}}$$

If the voltmeter resistance is not known, it may be measured by connecting the voltmeter in series with a low range ammeter and applying the line voltage. The resistance is then calculated by Ohm's Law, from the current indicated by the low range ammeter and the voltage indicated by the voltmeter. A quick check to determine whether or not it is necessary to deduct the watt loss in the voltmeter is to open the load circuit at point A, Fig. 5, and note the ammeter reading. If the deflection is too small to be read, then the watts loss in the voltmeter is small compared to the watts taken by the load and may be neglected. This is the most accurate method of measuring direct-current power when corrections are to be made for power lost in the instruments.

When approximate measurements are desired of low voltage loads (100 watts or under), the connections as shown in Fig. 6 are convenient. In this case the watt loss in the ammeter is so small it is usually neglected. However, when measurements are taken for loads carrying larger currents, the losses in the ammeter shunt and connections may become great enough to introduce an appreciable error in the results.

Let us assume that we desire to measure the wattage of a 25-watt incandescent lamp and that the instruments are connected as shown in Fig. 5. The instruments used are 0.300-ampere ammeter having a resistance of 0.17 ohms and a 150-volt voltmeter having a resistance of 15,000 ohms. The ammeter scale shown in Fig. 7 indicates 0.218 ampere. The voltmeter scale shown in Fig. 8 indicates 119.5 volts.

$$\text{Apparent Power} = \text{Volts} \times \text{Amperes}$$
$$= 119.5 \times 0.218 = 26.05 \text{ Watts}$$
$$\text{Voltmeter Watts} = \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}}$$
$$= \frac{119.5 \times 119.5}{15{,}000} = 0.95 \text{ Watts}$$
$$\text{True Watts} = 26.05 - 0.95 = 25.10 \text{ Watts}$$
$$\text{Per cent error} = \frac{0.95}{25.10} \times 100 = 3.78\%$$

Since the ammeter has a resistance of 0.17 ohm and is carrying 0.218 amperes, the voltage drop across it is, by Ohm's Law,

$$\text{Volts} = \text{Amperes} \times \text{Ohms}$$
$$= 0.218 \times 0.17 = .037 \text{ volt}$$

The true line voltage is then the sum of the voltage across the load plus the drop across the ammeter.

$$\text{Line Volts} = \text{Load Volts} + \text{Drop across Ammeter}$$
$$= 119.5 + .037 = 119.537 \text{ volts}$$

On the scale illustrated in Fig. 8, it is practical to read only to the nearest half of a scale division which is 0.5 volt. Therefore, with the instruments connected as shown in Fig. 6 and the same line voltage as in Fig. 5, the voltmeter would still indicate a reading of 119.5 volts. However, we will use the calculated figure given above in order to work out the error in this method of measurement.

If the voltmeter be connected outside the ammeter, as shown in Fig. 6, the ammeter will read the true current passing through the lamp. This current will be equal to the ammeter reading for Fig. 5 less the current passing through the voltmeter.

$$\text{Voltmeter Current} = \frac{\text{Volts}}{\text{Ohms}}$$
$$= \frac{119.5}{15{,}000} = .008 \text{ ampere almost}$$

Current passing through the lamp is then

$$0.218 - 0.008 = 0.210 \text{ ampere}$$

$$\text{Apparent Power} = \text{Volts} \times \text{Amperes}$$
$$= 119.537 \times .210 = 25.102$$

Since the true wattage is 25.10 watts

$$\text{Error} = 25.102 - 25.10 = .002 \text{ watts}$$

$$\text{Per cent error} = \frac{.002}{25.10} \times 100 = .008\%$$

The error is so small as to be negligible.

When tests are made on larger loads requiring several thousand watts, the loss in the voltmeter becomes so small in comparison to the amount of power measured that it is negligible. However, the losses in the leads and connections between the point where it is

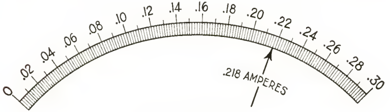


Fig. 7. Ammeter Scale

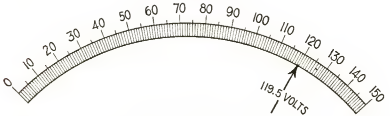


Fig. 8. Voltmeter Scale

convenient to connect the ammeter and the load to be measured become an important factor which must either be accounted for or eliminated from the calculations altogether.

The exact amount of losses in the leads and connections is difficult to determine, since they consist of not only the ohmic resistance of the conductors and shunt but also include the losses due to contact resistance whenever there are joints. Because contact resistance is a variable and not easily measured quantity, precautions should be taken in testing to eliminate its effect as much as possible.

When small currents are to be measured, the error due to contact resistance is small and, when care is taken in making con-

nections, will have very little effect on the meter indications. But when the currents are large, the contact losses become an appreciable amount of the power to be measured and, for accurate work, measurements must be so taken as to eliminate this error.

Fig. 9 shows the necessary connections for measuring the power delivered to a 20-horsepower 230-volt direct-current motor operating at almost full load. The purpose of this test is to determine whether or not the motor is overloaded. In order to demonstrate the error due to the two methods of connecting in the voltmeter, both connections are shown and values of resistance have been assumed for the resistance due to the leads and contacts.

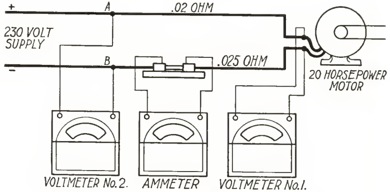


Fig. 9. Necessary Connections for Measuring Power Delivered to a 20-Horsepower D.C. Motor

In the plus lead, the resistance of connections from the motor to the point A at which the voltmeter is connected we will assume is 0.02 ohm, and the resistance of the negative lead including the shunt and connections is 0.025 ohms from the motor to the point B. The ammeter indicates 62.5 amperes and voltmeter No. 1 indicates 225 volts. Voltmeter No. 1 is connected directly to the motor terminals and therefore indicates the true voltage applied to the motor. The ammeter indicates the sum of the current taken by the motor plus that taken by the voltmeter.

$$\text{Apparent Power} = \text{Volts} \times \text{Amperes}$$
$$= 225 \times 62.5 = 14{,}062.5 \text{ watts}$$

The resistance of the voltmeter is 30,000 ohms

$$\text{Voltmeter No. 1 Loss} = \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}}$$

$$= \frac{225 \times 225}{30{,}000} = 1.69 \text{ watts}$$

$$\text{True Watts} = \text{Apparent Watts} - \text{Losses}$$

$$= 14{,}062.5 - 1.69 = 14{,}060.8 \text{ watts}$$

$$\text{Per cent error} = \frac{\text{Losses}}{\text{True Watts}}$$

$$= \frac{1.69}{14{,}060.8} \times 100 = 0.012\%$$

The error is so small that it is negligible.

Now let us consider the indications resulting if the readings are taken with the voltmeter connected on the line side of the ammeter as represented by voltmeter No. 2.

The total line resistance between the points A and B and the motor is

$$0.025 + 0.02 = 0.045 \text{ ohm}$$

$$\text{Voltage Drop in Line} = \text{Amperes} \times \text{Ohms}$$

$$= 62.5 \times 0.045 = 2.81 \text{ volts}$$

Therefore the line voltage indicated by voltmeter No. 2 is

$$\text{Line Voltage} = 225 + 2.81 = 227.81 \text{ volts}$$

The current taken by voltmeter No. 1 is

$$\text{Current} = \frac{\text{Volts}}{\text{Ohms}}$$

$$= \frac{225}{30{,}000} = 0.0075 \text{ amperes}$$

As this is much too small an amount to be read on the scale of the ammeter, the indication will still be 62.5 amperes.

$$\text{Apparent Wattage} = \text{Volts} \times \text{Amperes}$$

$$= 227.81 \times 62.5 = 14{,}238.1 \text{ watts}$$

$$\text{Error} = \text{Apparent Wattage} - \text{True Wattage}$$

$$= 14{,}238.1 - 14{,}062.5 = 175.6 \text{ watts}$$

$$\text{Per cent error} = \frac{\text{Losses}}{\text{True Watts}} \times 100$$

$$= \frac{175.6}{14{,}062.5} \times 100 = 1.25\%$$

While this error is small, it is uncertain and difficult to measure, therefore, the results obtained from the indications of the ammeter and voltmeter No. 1 are to be preferred.

The watts indicated may now be converted into horsepower by dividing by 746, since 746 watts is equal to one horsepower.

$$\text{Horsepower} = \frac{\text{Watts}}{746}$$

$$= \frac{14{,}062.5}{746} = 18.9$$

The motor is therefore not overloaded, since it is rated at 20 horsepower.

ALTERNATING-CURRENT MEASUREMENTS

Alternating Currents. An electric current which flows back and forth in a circuit at regular intervals is called an alternating current. When the current rises from zero to a maximum, returns to zero, increases to a maximum in the opposite direction, and finally returns to zero again, it is said to have completed a **cycle.** In alternating-current circuits this cycle of changes is repeated regularly and continuously. The number of cycles per second is called the **frequency.** Thus a current which rises to a maximum in each direction 60 times a second is said to have a frequency of 60 cycles.

If a resistance of one ohm, as measured by direct current, has no inductance and is so designed that alternating current in flowing through it does not produce any secondary effects, such as eddy currents or skin effect, it offers a resistance of one ohm to alternating current.

When an alternating-current ampere flows through such a resistance, the drop across its terminals is equal to one alternating-current volt.

An alternating-current ampere is that current which, flowing through a given ohmic resistance, will produce heat at the same rate as a direct-current ampere.

The above values of current and voltage are **effective values.** The actual instantaneous maximum of an alternating current is 1.4 times the effective value.

The power in a direct-current circuit under steady conditions is always given as the product of the volts across the circuit and the current in amperes flowing in the circuit. This same rule applies to alternating-current circuits, provided that only **instantaneous** values of amperes and volts are considered. The **average power,** however, is not necessarily the product of the effective volts and effective amperes as measured by a voltmeter and an ammeter.

In direct currents only resistance need be considered. Due to the cyclic variation of alternating currents, the presence of inductance and capacity cause what is known as a **phase difference** between the current and voltage.

A voltmeter will indicate the true voltage applied in an alternating-current circuit and an ammeter will indicate the true current. The product of these two readings is known as the **apparent power.** Only when the circuit is made up of pure resistance is the apparent power equal to the true power. When the current and voltage are not exactly in phase, a condition created by the presence of inductance or capacity, the true power will be less than the apparent power. The true power is obtained from a wattmeter reading. The ratio of the true power to the apparent power is called the **power factor** and is usually expressed in per cent. Writing this as a formula, we have

$$\frac{\text{True Power}}{\text{Apparent Power}} \times 100 = \frac{\text{Watts}}{\text{Volts} \times \text{Amperes}} \times 100$$
$$= \text{Per Cent Power Factor}$$

The power factor expresses that percentage of the apparent power which is true power in an alternating-current circuit. Where large amounts of power are to be measured, the true power is expressed in terms of kilowatts and the apparent power as kilovolt-amperes. One kilowatt equals one thousand watts and one kilovolt-ampere equals one thousand volt-amperes.

The Wattmeter. The wattmeter, Fig. 10, is a very important instrument in alternating-current measurements as it provides the only method of determining the true power. Fig. 11 shows a diagram of the internal connections of a Weston dynamometer type wattmeter. The moving coil is wound with fine wire and is practically identical with the moving coil of the dynamometer voltmeter.

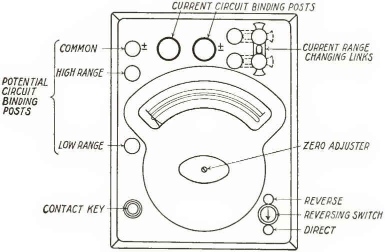


Fig. 10. Wattmeter
Courtesy of Weston Electrical Instrument Company

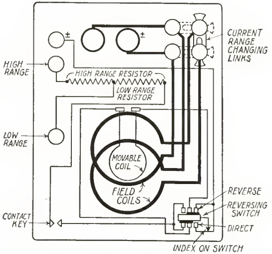


Fig. 11. Internal Connections for Dynamometer Type Wattmeter
Courtesy of Weston Electrical Instrument Company

It is connected across the line in series with a high resistance. The current is led into this coil through springs. The two field or current coils are wound with a few turns of heavy wire, capable of carrying the load current or a portion of it as supplied by a current transformer.

As there is no iron present, the field due to the current coils is proportional to the load current at every instant. The current in the moving coil is proportional to the voltage at every instant. Therefore, for any given position of the moving coil, the torque is proportional at every instant to the product of the current and

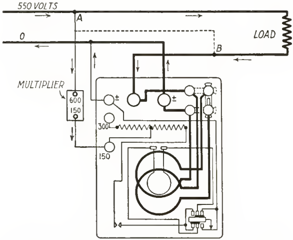


Fig. 12. Correct Method of Connecting a Wattmeter into a Circuit

voltage or to the instantaneous power of the circuit. The moving coil takes a position corresponding to the average torque, thus indicating the true power in the circuit to which the wattmeter is connected.

It should be noted in Fig. 11 that the voltage terminal is connected directly to one end of the potential coil. This terminal should always be connected directly to the side of the line to which the current coil is connected. Fig. 12 shows the correct method of connecting a wattmeter into the circuit. Since almost all of the potential drop between the two lines in the potential circuit takes place in the series resistance, the current and the potential coils are at the same potential. If the potential coil is connected to the

other side of the line, as shown in Fig. 13, the potential difference between the current and the potential coils is equal to the full line potential. In this diagram the current coils are considered as being at zero, or ground potential. The potential coil is then at the potential of the other side of the line, or 550 volts, and this is the difference of potential which exists between the current and the potential coils. This is a dangerous voltage, for the insulation of the instrument and electrostatic forces existing between the current and the potential coils may cause an error in the indicated reading. *The potential terminal marked + must always be connected to the same side of the circuit (same potential) as the current coils.*

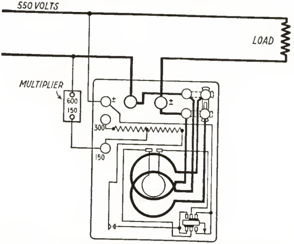


Fig. 13. Incorrect Method of Connecting a Wattmeter's Potential and Current Terminals to a Circuit

When a multiplier is used, it must be connected to the range of the instrument to which it is adjusted. For example, suppose we have an instrument with potential ranges of 150 and 300 volts, and a multiplier for 600 volts. The multiplier will have a binding post marked 150V and one marked 600V.

Connect the binding post of the multiplier marked 150V to the binding post of the wattmeter which is marked 150; then connect the 600V binding post of the multiplier to that wire of the circuit which does not contain the current coil circuit of the wattmeter.

One of the current coil terminals is also marked ±. If, at the time the wattmeter is connected into the circuit, it is assumed

that the current flows in only one direction, as indicated by the arrows in Fig. 12, and that the potential and current circuits are each connected so that the current will enter at the terminals marked $\pm$, then the instrument will read direct. That is, the reading will be obtained when the reversing switch is in the **direct reading** position.

Simple Wattmeter Connections. Since alternating-current instruments require more power to operate than direct-current instruments, it is even more important that correct connections be employed and the proper corrections be applied when they are used.

In order to measure power correctly, the wattmeter current coil should carry the load current and the wattmeter potential coil with its series resistance should be connected directly across the load. Fig. 12 shows a wattmeter connected to measure the power taken by a certain load. With the connections as shown, the true load current passes through the current coils, but the potential circuit measures the voltage drop across the load plus the voltage drop across the wattmeter current coils. Therefore the wattmeter reads too high by the amount of power consumed in its own current coils. Under these conditions the true power delivered to the load is equal to the power indicated by the wattmeter less the watts loss in the current coils. This instrument loss may be calculated by multiplying the current squared (times itself) by the resistance of the wattmeter-current-coil circuit. When current transformers are used, it is difficult and often impracticable to allow for the losses with this method of connecting. However, if the loss is appreciable, it may be measured directly by changing the one potential lead from the point A to the point B, as shown by dotted lines in Fig. 12.

Fig. 14 shows the simplest case of connections where the wattmeter is connected directly to the load. It will be noted that the current coils carry both the load current and the current required by the potential circuit, so that the indication of the wattmeter includes the power lost in its own potential circuit.

When accurate measurements are required, this is the connection usually employed as the correction for instrument loss may be easily and accurately obtained. To determine the loss in the potential circuit of the wattmeter by direct reading, it is necessary only to open the circuit at the load point A in Fig. 12 and con-

nect that lead to B. The resulting reading is the wattmeter loss and it is subtracted from the total reading obtained with connection A closed.

The watts loss in the potential circuit may also be easily calculated when the potential circuit resistance is known.

The watts loss is equal to the voltage squared (times itself) divided by the potential circuit resistance in ohms.

$$\text{Watts Loss} = \frac{\text{Volts} \times \text{Volts}}{\text{Ohms}}$$

The current and potential circuits of a wattmeter each have a rating corresponding to the current and voltage of the circuit to which the instrument is intended to be connected. A wattmeter is rated in amperes and volts rather than in watts, because the indicated watts show neither the amperes in the current coils nor the voltage across the potential circuit. If the current through an ammeter should exceed the rating of the instrument, the pointer goes off scale and so warns the user. The same is true of applying excessive voltage to a voltmeter.

A wattmeter current coil may be considerably overloaded and yet the power factor of the load be so low that the pointer is still on the scale. For this reason it is ordinarily common practice to connect an ammeter and a voltmeter in conjunction with the wattmeter so that the current and voltage applied to the wattmeter may be known. It is usually recommended that the ammeter be connected directly in series with the wattmeter current coil and that the voltmeter be connected in parallel with the potential circuit.

At top of page 19 is a copy of the certificate giving the instrument data included in the cover of a Weston Model 310 Portable Wattmeter.

This indicates that with the field coils connected in series the normal current capacity is five amperes, but that for short periods (long enough to obtain readings) currents as high as ten amperes may be passed through the current or field coils when connected in series. When the field coils are connected in parallel, the normal current for continuous duty is ten amperes; but for short periods (long enough to obtain readings) currents as high as twenty amperes may be allowed to pass through the coils. While these maximum

Model No. 310 Wattmeter Serial No. 7774

Capacities

Form 1

Field in Series: Normal current 5 amps. Maximum current 10 amps.
Field in Parallel: Normal current 10 amps. Maximum current 20 amps.

Ranges

Fields in Series

150-volt circuit, multiply scale readings by ½
300-volt circuit, multiply scale readings by 1
600-volt multiplier, multiply scale readings by 2

Fields in Parallel

150-volt circuit, multiply scale readings by 1
300-volt circuit, multiply scale readings by 2
600-volt multiplier, multiply scale readings by 4

Scale 1.5 kilowatts

Potential Circuit

Normal Volts	Maximum Volts	Resistance .25° C.
150	250	6953.5 ohms
300	450	13907.0 ohms
600 multiplier		27733.0 ohms

Approx. resistance of field coils in series = 0.03 ohm; parallel .0075 ohm.
Approx. self-inductance field coil in series = .000037 henry; parallel .000009
Approx. self-inductance potential circuit = .0034 henry

currents are allowed, particular care must be taken whenever the normal current is exceeded. Many wattmeters have been burned out or their readings impaired because they were operated at currents above the normal current recommended by the manufacturer. It is therefore recommended that, in all cases where it is possible, the rated normal current recommended by the manufacturer be not exceeded.

Next we find a list of the ranges and multiplying factors. For each combination of current coil arrangement and potential tap there is a particular multiplying factor by which the scale reading must be multiplied in order to obtain the correct amount of power as indicated by the wattmeter. It is of great importance that the right multiplying factor be used as otherwise the value of an accurately taken reading may be completely destroyed and a considerable error introduced into the results. A careful person refers to the wattmeter certificate every time the wattmeter is used in order to insure that it is properly connected and that the correct multiplying factor is used.

Data is also given for the potential circuit. As in the case of the current coils, a normal and a maximum rating are given. Except under unusual conditions the normal values should never be exceeded; when they are, the voltage should be applied to the meter only long enough to obtain the reading desired. The resistance values of the various potential circuits are also given. These values are useful when it is desired to calculate the watts dissipated in the potential circuit for instrument loss corrections.

The approximate resistance of the field coils is also given in order that approximate losses in the field coils may be estimated for rough calculations. Approximate values of self-inductance of the current and potential circuits are given but are used only in special cases very seldom met with in testing.

WATTAGE AND POWER-FACTOR MEASUREMENTS

Single-Phase Measurements. The measurement of power supplied to a load from an alternating-current supply may be effected either directly or through proper instrument transformers. When the values of current and voltage do not exceed the normal rating of the instruments used, the measurements are usually taken with the instruments connected directly in the circuit. If measurements are to be made where the voltage is high or the current exceeds the rating of the instruments, then instrument transformers must be used.

Fig. 14 shows a wattmeter connected directly to the circuit to measure the power supplied to a single-phase load. If the voltage is greater than 150 volts, a multiplier is connected in series with the potential circuit, as shown in Fig. 15. If the current is greater than the rated current of the wattmeter, a current transformer should be used, as shown in Fig. 16. When measurements are made on high voltage circuits, it is accepted practice to use instrument transformers for both current and potential measurements in order to insulate the indicating instruments from direct contact with the power lines, as shown in Fig. 17.

A group of instruments connected through instrument transformers to a single-phase load is shown in Fig. 18. The potential transformer has a ratio of 120 to 1, that is, the line voltage is 120

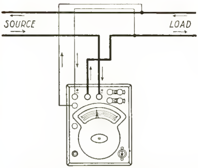


Fig. 14. Wattmeter Connected Directly to the Circuit

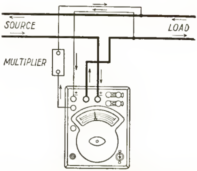


Fig. 15. Showing How Multiplier Is Connected to a Wattmeter When Voltage Is Greater Than 150 Volts

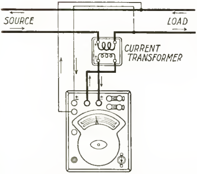


Fig. 16. Showing How Current Transformer Is Connected to a Wattmeter When Current Is Greater Than Rated Current of Wattmeter

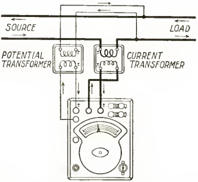


Fig. 17. Showing Use of Potential and Current Transformers Connected to a Wattmeter When Measurements Are Made on High Voltage Circuits

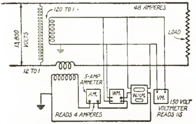


Fig. 18. Typical Connections of Instrument Transformers and Instruments for Single-Phase Measurements

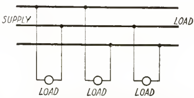


Fig. 19. Three-Phase Line Supplying Power to Three Single-Phase Loads

times that indicated by the voltmeter. When the voltmeter indicates 115, the line voltage is 13,800 volts. The current transformer has a ratio of 12 to 1. When the ammeter indicates 4 amperes, the load current is 48 amperes. Since both the potential and current circuits of the wattmeter are connected to the instrument transformer circuits, its indication must be multiplied by the ratio of both transformers to obtain the true wattage. The wattmeter indicates 345 watts, the true watts supplied to the load is then

$$\text{True Power} = 345 \times 120 \times 12 = 496{,}800 \text{ watts}$$

$$\frac{496{,}800}{1000} = 496.8 \text{ kilowatts}$$

The apparent watts delivered to the load is equal to the current delivered to the load multiplied by the volts across the load. Since the power taken by the load is great compared to the losses in the imstruments, they are neglected.

$$\begin{aligned} \text{Apparent Power} &= \text{Volts} \times \text{Amperes} \\ &= 13{,}800 \times 48 = 662{,}400 \text{ watts} \end{aligned}$$

The power factor in per cent is equal to the true power divided by the apparent power and multiplied by 100.

$$\begin{aligned} \text{Power Factor} &= \frac{\text{True Power}}{\text{Apparent Power}} \times 100 \\ &= \frac{496{,}800}{662{,}400} \times 100 = 75\% \end{aligned}$$

Three-Phase Measurements. Since almost all new developments in the application of electric power are favoring the three-phase system, we will study briefly the method most commonly employed in making three-phase wattage measurements.

A three-phase system consists of three single-phase circuits. Usually three wires are used to transmit three-phase power. A single-phase load may be attached to any two of the wires, as is shown in Fig. 19. A three-phase load, such as a motor, requires that all three lines be connected to it.

The true watts delivered to a three-phase load when three wires are employed may be measured by the use of two wattmeters, as is shown in Fig. 20. A wattmeter is connected in series with each of

two of the three lines. One side of each wattmeter potential circuit is connected to the same line as the current coil is connected, and the other potential terminal is connected to the third line. Care should be taken that the potential terminal marked + is connected to the same line as the current coil of the wattmeter.

Under ordinary conditions, when the power factor is greater than fifty per cent, the two wattmeter readings are added to give the total true watts supplied to the load. When the power factor is less than fifty per cent, the smaller wattmeter reading is subtracted from the larger wattmeter reading to obtain the correct value of true watts.

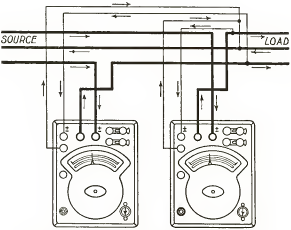


Fig. 20. The Use of Two Wattmeters to Measure True Watts Delivered to a Three-Phase Load When Three Wires Are Used

Unless it is definitely known from previous experience that the power factor is greater than fifty per cent, a check should be made at the time the readings are taken to determine whether to add or to subtract the wattmeter readings to obtain the correct result. The simplest method of checking this is to open the line in which the high reading wattmeter is connected. When this is done, the wattmeter having the low reading is left in a simple single-phase circuit and therefore must indicate true watts. If under these conditions the direction of deflection is the same as when the three-phase measurements were taken, the wattmeter readings are added. Should the deflection be in the reverse direction, then the smaller

wattmeter reading should be subtracted from the larger. The actual value obtained from the single-phase measurement is useless; it is only the direction of deflection we are interested in.

When it is impractical to open one of the line wires as is required to make the single-phase test described above, the following method may be employed. Leaving all other connections unchanged, transfer the potential circuit connection of the low reading wattmeter from the common line to which both wattmeter potential circuits are connected to the line in which the current coil of the high reading wattmeter is connected.

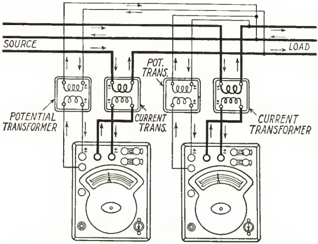


Fig. 21. The Use of Instrument Transformers When Line Voltage Is High and Currents to be Measured Are Greater Than Rating of Wattmeters

If the deflection of the low reading wattmeter does not change in direction, the sum of the original readings of the two wattmeters gives the total power. If the deflection of the low reading wattmeter reverses, subtract the original readings of the wattmeters.

When the line voltage is high and the currents to be measured are greater than the rating of the wattmeters employed, instrument transformers must be used. Fig. 21 shows two wattmeters with potential and current transformers connected for measurement of power in a three-phase circuit.

In a single-phase circuit, the apparent power is equal to the current multiplied by the voltage The apparent power in a three-

phase circuit is, of course, greater than a similar single-phase circuit when the voltage between lines and the current are equal. In a three-phase circuit, the apparent power is equal to the voltage between lines multiplied by the line current and multiplied by 1.73. Expressed as a formula, we have

$$\text{Apparent Power in Watts} = 1.73 \times \text{Volts} \times \text{Amperes}$$

To measure the power taken by a one-horsepower three-phase 220-volt motor and the power factor of the circuit, the instruments are connected as shown in Fig. 22 and the readings are as indicated. Wattmeter No. 1 indicates 275 watts and wattmeter No. 2 indicates

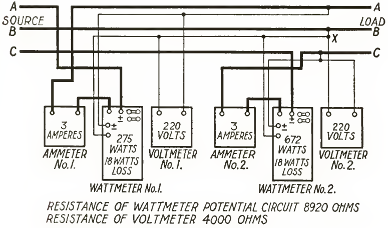


Fig. 22. Connections for Measuring Power in Three-Phase Circuits

672 watts. Wattmeter No. 1 is the low reading instrument and should be checked to determine whether or not its indicated watts should be added or subtracted. To check by the single-phase method, the line connected to the current coil of wattmeter No. 2 is opened at the load. This is the line marked *C*. The direction of deflection is the same as when the reading 275 was obtained, therefore, its reading is to be added to the reading of wattmeter No. 2. We can also check the deflection of wattmeter No. 1 by removing the potential connection *X* from the line *B* and connecting it to the line *C*, leaving all other connections as they were for the original measurements. This also indicates that the wattmeter

deflection is in the same direction as when the readings were taken and that the reading should be added to the reading obtained from wattmeter No. 2. Only one of these checks need be made, as the result of either is the same.

The instrument losses may also be checked directly by opening the line circuits at the load and observing the deflection of each of the wattmeters. In the case of the connection shown in Fig. 22, both wattmeters indicate 17.5 watts. The losses indicated should be subtracted from the indicated values before they are added together to obtain the true power supplied to the load. These losses may also be calculated as follows:

$$\text{Loss in Wattmeter Potential Circuit} = \frac{\text{Volts} \times \text{Volts}}{\text{Resistance}}$$

$$= \frac{220 \times 220}{8920} = \frac{48{,}400}{8920} = 5.4 \text{ watts}$$

$$\text{Loss in Voltmeter Circuit} = \frac{\text{Volts} \times \text{Volts}}{\text{Resistance}}$$

$$= \frac{220 \times 220}{4000} = \frac{48{,}400}{4000} = 12.1 \text{ watts}$$

The total loss then for each wattmeter correction is

$$\text{Total Loss} = 5.4 + 12.1 = 17.5 \text{ watts}$$

Since we know that the wattmeter readings are to be added and the watts loss as indicated by each wattmeter, we are now ready to calculate the power delivered to the load and the power factor.

$$\text{Wattmeter No. 1 corrected for losses} = \text{Indicated Watts} - \text{Losses}$$

$$= 275 - 17.5 = 257.5$$

$$\text{Wattmeter No. 2 corrected for losses} = 672 - 17.5 = 654.5$$

$$\text{True Power} = \text{Wattage No. 1} + \text{Wattage No. 2}$$

$$= 257.5 + 654.5 = 912 \text{ watts}$$

$$\text{Apparent Power} = 1.73 \times \text{Volts} \times \text{Amperes}$$

$$= 1.73 \times 220 \times 3 = 1141.8 \text{ watts}$$

$$\text{Power Factor} = \frac{\text{True Power}}{\text{Apparent Power}} \times 100$$

$$= \frac{912}{1141.8} \times 100 = 80\%$$

Power-Factor Meters. In a direct-current circuit, power is determined by the product of volts times amperes. In an alternating-current circuit, it is necessary to introduce a third factor, called the power factor, the value of which depends upon the characteristics of the circuit and load. In practice these characteristics cause the current and voltage to be out of phase with one another so that the effective value of the current is less than its actual value. Power factor is the ratio of the true power in watts to the apparent power in volt amperes expressed in per cent.

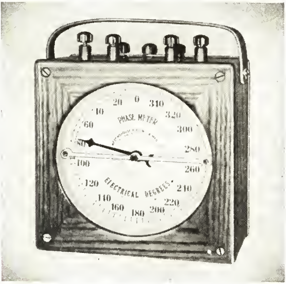


Fig. 23. Power-Factor Meter
Courtesy of Westinghouse Electric Corporation, Pittsburgh, Pa.

The importance in keeping the power factor high lies in the fact that for any given voltage and power the current increases very rapidly as the power factor becomes less than 100 per cent. If, for instance, we consider a load consuming a fixed amount of power which requires, at 100 per cent power factor, 100 amperes; then when the power factor drops to 90 per cent, 111 amperes are required; and if the power factor drops to 80 per cent, 125 amperes are required. The increase in current does not do useful work but, on the contrary, it results in losses, due to the heating effect on conductors and other equipment. In recognition of the losses due

to low power factor, most electric power companies base their rates for power to large consumers on the power factor of the customer's load. It is therefore to the customer's advantage to maintain as high a power factor as possible.

The power-factor value can be obtained by calculations, using the readings of wattmeters, ammeters, and voltmeters. This, however, is a laborious and time-consuming task impractical for commercial work where continuous watch of the power factor is required. For this kind of service, a special instrument known as a power-factor meter, Fig. 23, has been developed to indicate directly the power factor. Mechanically the power-factor meter is a special application of the electrodynamometer principle. The power-factor meter, however, differs from other indicating instruments in one respect, it has no springs to control the movement of the movable coil and pointer. With no current applied to the instrument, therefore, the pointer may stand at any point on the scale.

Single-phase power-factor instruments are relatively simple to connect to the circuit for correct indication. Three-phase instruments, on the other hand, may offer considerable difficulties if the correct connections are not made when the instrument is installed.

The most common mistake in connecting three-phase power-factor meters is to have reversed phase rotation. This does not alter the percentage reading but causes the pointer to stand at the wrong end of the scale so that, for example, an 80 per cent lagging power factor would give an 80 per cent leading indication. This may be corrected by reversing the potential leads *a* and *c*, as shown in Fig. 24. Fig. 25 shows a similar instrument except that the line voltage is greater than the internal resistance of the instrument was designed for and an external resistance similar to the multiplier used with voltmeters and wattmeters is supplied to extend the range of the potential circuit.

If the trouble is other than reversed phase rotation, the next step is to determine the correct power factor by means of the voltmeter, ammeter, and wattmeter method. It is important to note whether or not the power factor is within the scale limits of the power-factor meter. If the power factor is lower than the meter is capable of indicating, then it must be raised by changing the nature of the load before further tests can be made. Next measure the

line voltages. This should be done at the meter studs when the resistance is self-contained and at the line side of the external resistance box when such is provided. That is, measure the voltage between *a* and *b*, between *b* and *c*, and between *c* and *a*. They should be equal or very nearly so. If the voltages are not approximately equal, the potential circuit should be checked carefully until the difficulty is located.

If the meter does not operate, that is, if no change in position of the pointer occurs when the load comes on or goes off, an ammeter should be connected in series with the current coil circuit *d* or *e*. Check to see that there is a circuit through the current coil.

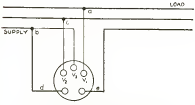


Fig. 24. The Connection of a 3-Phase Power-Factor Meter

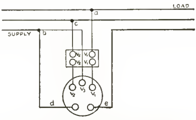


Fig. 25. The Connection of a 3-Phase Power-Factor Meter with External Resistance

If the instrument does not operate with current in the current coil circuit and all three potentials equal, then the movable system is burned out or the potential circuit is open. In either case, the instrument should be returned to the manufacturer for repair.

If the meter does tend to operate when the load is applied but does not indicate a power-factor value approximately equal to the value calculated from the voltmeter, ammeter, and wattmeter readings, then proceed as outlined below until the numerical value of the power factor indicated is correct. Then if the instrument indicates "lead" instead of "lag," interchange wires *a* and *c*.

(a) Interchange *d* and *e*.
(b) Place wire *a* on V_2, *c* on V_3, and *b* on V_1.
(c) Interchange *d* and *e*.
(d) Place *a* on V_3, *c* on V_1, and *b* on V_2.
(e) Interchange *d* and *e*.

When an external resistance box is used, make changes in the connections between the line and the resistance box, not in the con-

nections between the resistance box and the instrument. The pointer should now be on the scale and indicate the correct numerical value. If this does not happen, then re-check the indications of the ammeter, voltmeter, and wattmeter, as one or more of these may be in error instead of the power-factor meter.

After obtaining the correct connections, the power-factor meter may be checked in the following manner:

Remove wire *a* and the pointer should indicate end of scale on the "lag" side.

Replace wire *a* and remove wire *c* and the pointer should indicate end of scale on the "lead" side.

With *c* off, connect V_1 with V_2 at the meter studs when the resistance is contained within the meter or at the line side of the external resistance box when such is used. The meter should now indicate unity (100).

When the power factor of approximately 50 per cent is encountered, this scale check will show the meter to have torque and the pointer will act sluggish when checking one end of the scale. In this event use the other potential wire for both V_1 and V_2 when checking the scale ends and center.

MEASUREMENTS OF RECTIFIER CURRENTS

Over ninety per cent of the electrical energy produced at the present time is generated and transmitted as alternating current. The greater portion of this energy is utilized as alternating current to operate motors, electric furnaces, electric lights, and many other types of electrical appliances. However, there are still many cases where the electrical energy must be in the form of direct current, even though the available supply of energy is alternating current. Direct current must be used for charging storage batteries, electroplating work, electrochemical work, for the control of magnetic clutches, and the like.

Since the power supply in the majority of cases is alternating current, this alternating current must in some manner be changed to direct current. There are several methods of accomplishing this, the most common being motor-generator sets, synchronous rotary converters, and rectifiers.

Current and power measurements in direct-current circuits supplied from motor-generators or rotary converters are made the same as any other direct-current measurements, as the current is of a continuous nature which does not vary periodically and is usually considered constant during the time of measurement. Rectifiers, on the other hand, produce pulsating currents which are similar to alternating currents in that they vary periodically, but the quantity of electricity transferred in one direction is greater than that transferred in the opposite direction, that is, the average value of the current in one direction is greater than that in the opposite direction.

Rectifier currents being neither direct current nor true alternating current require special care in measuring in order to obtain the true values desired. There is no general method for making measurements of rectifier currents, the method and instruments necessary to employ in any particular case depend upon the purpose for which the current is to be used. The value assigned to pulsating currents is a conventional one, depending upon the effect the current produces in the circuit or apparatus through which it passes. The unit of current in a pulsating current circuit may be defined as equal to the value of a direct current which would produce the same effect under the same conditions. For example, as will be seen later, some effects vary as the first power of the instantaneous current values, while other effects vary as the second power (current squared or times itself).

In general, two types of instruments are used to measure currents and voltages in rectifier circuits. Direct-current instruments of the permanent magnet type are used for measurements where the effect varies with the first power or average value of the current. Alternating-current instruments of the moving iron and electrodynamometer type are used where the effects vary as the second power or heating value. Direct-current and alternating-current instruments indicate differently on pulsating currents, so it is necessary for each type of measurement that the correct type of instrument be selected. To show how this selection is made, a few of the more important applications will be described.

Battery Charging. The amount of charge in a storage battery produced by the charging current is proportional to the quantity of electricity passed through the battery, usually measured in ampere

hours. Since the quantity of electricity is equal to the average value of the current multiplied by the time the current has been passing, the proper instrument to use is one which measures the average value, that is, the permanent magnet moving coil direct-current meter.

Electroplating. As in battery charging, the amount of metal deposited in plating baths is proportional to the quantity of electricity or average value of current passing through them. It is therefore necessary to use a permanent magnet movable coil type direct-current instrument.

Electromagnetic Devices. Since the magnetic force produced by an electromagnet is proportional to the current supplied to its winding times the number of turns in the winding, it is the average value of the current that should be measured. The permanent magnet movable coil type direct-current instrument is used for this purpose.

Heating Appliances. In electrical heating devices the heat developed is proportional to the wattage produced in them, which is equal to the current squared times the resistance of the device. Since the heating effect is proportional to the square of the current, it is necessary to use a type of instrument whose indication is proportional to the square of the current. The electrodynamometer or movable iron type alternating-current instruments are necessary to measure the effective values of alternating or pulsating current used for heating devices.

Incandescent Lamp Loads. The candle power of a given lamp is dependent upon the temperature of the filament, therefore, the effect of the current is proportional to its heating value. Since the heating value is proportional to the square of the current, the movable iron or electrodynamometer type alternating-current instrument must be used.

Measurement of Power. The average power in watts delivered to any load by a pulsating current will be correctly indicated by an electrodynamometer type wattmeter. However, it is impractical to attempt to make power-factor measurements in pulsating current circuits.

REVIEW QUESTIONS

1. What is the difference between *work* and *power?* Give the formula for each.

2. What is the value of a *horsepower* in foot pounds per minute? State the formula.

3. What is the formula for electrical power in *watts?* In *kilowatts?*

4. What is the equivalent of 1 horsepower in watts? Of 1 kilowatt in horsepower?

5. Why is the method of connecting meters shown in Fig. 5 on page 210 the best when the current is large?

6. Why is the method shown in Fig. 6 on page 210 the best when the current is small?

7. What is *apparent power? True power?* When is the apparent power equal to the true power?

8. What is *power factor?* How is it expressed?

9. What type of a meter will indicate true power in an alternating-current circuit?

10. Why is it necessary to connect the potential terminal marked + to the same side of the circuit as the current coils, when connecting a wattmeter to a circuit?

11. When a wattmeter is to be used on high-voltage circuits, what is the common method of connecting it to the line?

12. In a three-phase circuit of unknown power factor, where two wattmeters are used to measure true watts, how would you determine whether to add or to subtract the two wattmeter readings? Assume that it is impractical to open one of the line wires.

13. When measuring rectified currents, under what condition must you use direct-current type meters? Under what conditions must you use alternating-current type meters?

14. At what value of power factor is it most advantageous to operate? Why?

15. If the effective voltage of a *sinusoidal wave form* is 100 volts, what is the maximum instantaneous value?

APPLICATIONS TO INDUSTRY

1. By means of a wattmeter, ammeter, and voltmeter how would you determine the *power factor* of a single-phase circuit?

2. In a three-phase circuit, the voltage between each pair of lines is 115 volts. If each line carries 20 amperes, what is the *apparent power* in volt-amperes?

3. If a 220-volt, single-phase circuit is carrying 25 amperes and a power factor meter indicates .80 lag, what is the *true power* in watts?

4. If a circuit operating at fixed load required 100 amperes, with a power factor of 1.00, what current would the load require at a power factor of .90? At a power factor of .80?

5. In the problem in question 4, why wouldn't the added current perform any useful function?

6. Make a block diagram to indicate how you would connect a wattmeter to a single-phase line. Indicate the common polarities of the potential coil and the current coils.

7. Draw a simple block diagram to show the correct method of connecting two wattmeters to a three-phase line. Indicate the common polarities on the wattmeters.

8. In a three-phase circuit on which no power-factor meter is used and for which the power factor is unknown, two wattmeters are used to determine the true watts delivered to the load. In this case one meter reads 300 watts, the other 600 watts. When the line, to which the higher reading wattmeter is connected, is broken, the deflection of the meter having the lower reading does not change direction. What is the *true power?* Would the *power factor* be more or less than 50 per cent?

9. In problem 8 assume that the lower reading wattmeter reverses its direction when we break the line to which the higher reading wattmeter is connected. What would the *true power* be? Would the *power factor* be more or less than 50 per cent?

10. In problem 8 if the lines to the load were broken, and each of the wattmeters indicated 17.5 watts with no load, what would be the *true power* corrected for instrument losses?

INDUCED CURRENTS

This is one of the most interesting parts of the study of electricity, the part that has played an important role in making civilization what it is today by banishing endless drudgery, and thus contributing much to human happiness and well-being. This interesting subject is *the generation of electricity by mechanical means*, and *the putting of this electricity to work for us.* Today, electricity performs our small everyday tasks as well as our large ones. Above all, it produces mechanical power, to the extent that electricity has become one of the most efficient sources of power in the world today.

The machine which produces mechanical power from electricity also may be a producer of electrical current. In fact, it was for the production of electrical current that this machine was originally devised and intended. We now recognize, however, that any direct-current generator makes an efficient motor for converting electrical current into mechanical power.

This machine, which serves either as motor or as generator, may be simple in its construction, or it may be complex. Its complexity is caused simply by the addition of various features for better performance in some special field. It is, of course, the simple forms of it that you will study first. By obtaining a good knowledge of the basic principles of the simple machines, it will be easy to apply them to the more complicated machines.

The machine is basically a contrivance of insulated (magnet) wire and iron in an arrangement that will obtain the full effects of the magnetism from the electrical circuit. For we actually get all of the power, not from the electrical circuit, but from the magnetic circuit of this machine. The best magnets, and the ones employed in electrical machinery of great power, are those in which the magnetism is produced electrically. Since the power in these machines depends entirely upon the magnetism produced by electricity, it is necessary that you understand just how this is done, if you hope to understand the operation of these machines.

MAGNETIC FIELDS AROUND A WIRE

The first thing you must fix in your mind is that there is always a magnetic field around an electrical current. Since there is not usually a current flowing unless it is conveyed along its way by a conductor, and since this conductor is usually a wire, we might say that a wire carrying a current always has a magnetic field around it. This magnetic field always lies about the wire in a position at right angles to it. Furthermore, it lies about the wire in concentric

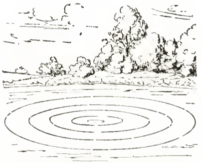


Fig. 1. A Pebble Dropped into a Pond or Lagoon Starts Tiny Waves Which Form Complete Circles

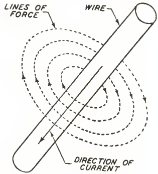


Fig. 2. Lines of Force of the Magnetic Field Lying at Right Angles to a Wire Carrying a Current

circles, not spirals, and these circles extend out from the wire in distances that depend upon the strength, or amount, of the current flowing through the wire.

If you toss a pebble into a quiet pond or lagoon, Fig. 1, you will observe, starting at the point where the pebble dropped into the water, tiny waves, forming in complete circles, expanding in size and extending away from their point of origin, each wave followed, in rapid succession, by many others which are its exact counterpart.

This simple experiment illustrates closely just how magnetism lies about a wire carrying a current. The stone entering the water must be considered as the wire carrying the current. Imagine that there is an actual wire sticking up out of the water as these wave circles are forming. Then you will have a vivid picture in your mind of the magnetic field that lies around the wire, at the surface of the water. At every other point on the wire a similar field exists.

Magnetic Lines of Force. Magnetic fields are made up of many individual actions, called *lines of force*. It is these that you trace when you study the magnetic field. Fig. 2 shows these lines of force encircling a wire, similar to the action of the waves about the pebble that was tossed into the pool. It illustrates the right angle position which these lines of force assume around a wire carrying a current.

If you go a little deeper into this phenomenon of the magnetic field about a current, you find that the lines of force maintain certain directions with respect to the current in the wire, and also that you are able to determine these directions, identify them, and make use of this knowledge.

Experiment Showing Lines of Force Around a Wire. To find the direction of the lines of force, you must use a certain instrument. This instrument is the simple magnetic compass used by woodsmen, or by boy scouts, for determining their directions in the woods. You can buy one at the 10-cent store. Then obtain a stiff piece of cardboard, or a cigar-box lid, a piece of plain white paper, a short length of brass rod, or heavy copper wire, some iron filings (If you have access to a machine shop, you can get these by the box full. If not, use a coarse file on a piece of scrap cast iron until you have a sufficient quantity.), some connecting wire and a source that will supply current. A storage battery is by far the best source of current supply for these experiments, and if it is at all possible, you should obtain the use of one. If you are not able to manage this, then you may substitute several No. 6 dry cells. The iron filings can be put into a kitchen saltshaker and used conveniently.

Set up the apparatus for this experiment, as shown in Fig. 3. A hole should be made through the board that is a tight fit for the brass rod, or heavy copper wire, whichever you are to use. Place this in position in the hole so that it will be perpendicular to the surface of the board. Push the clean white paper down over the rod or wire so as to make a smooth surface for the board. Prop up this complete assembly, in a level position, so that you have clearance for the part of the rod which protrudes below the board. Use the connecting wire or cable to make a connection from the lower end of this rod to the negative terminal of the battery. Connect a length of this wire to the top of the rod, but do not make a connection to the positive terminal of the battery just yet. Now, sprinkle a light

film of iron filings on the paper, around the rod, covering the board with them for a distance of three or four inches away from the point where the rod enters the board.

Since the electrical circuit, as you have it arranged, is practically a short-circuit on the battery, the final electrical connection is to be made merely by holding the end of the wire against the battery post for the few seconds necessary to perform this experiment. Now that you are ready, make this contact. If a storage

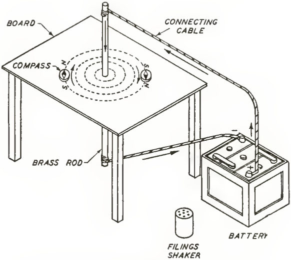


Fig. 3. The Magnetic Field Around a Coil Being Shown by Filings' Test

battery is used, the filings will fairly jump into place. If dry cells are used, you may have to tap the board gently with a pencil to assist them in forming. Observe that you have many definite circles of filings around the wire on the board. Do not keep the circuit closed longer than necessary to get these filings into position. Once they are in position, they will remain there until the board is jostled. These filings clearly indicate the magnetic paths about the conductor. They do this because each metal particle, being iron, tends to be drawn into such a position that the lines of force will run through the entire length of each, and in the circles in which the lines of force tend to run, due to the fact that these lines of force are strong enough to pull them around in this direction. After all, this is

merely the action of the magnetic compass. But since these tiny filings have no way of indicating in which direction they are pointing with respect to the magnetism, you cannot tell from them the direction in which the lines of force are flowing. You can tell only that they do exist, and that they flow in circles.

It now remains to find out the actual direction of travel of these lines of force, with respect to the direction in which the current is flowing through the wire. To do this you now make use of the magnetic compass. If you will refer again to Fig. 3, you will see that the current flows down through the rod when the connections are made, since you arranged to have the positive battery terminal connected at the top of the rod. If the current flows down through this rod, it flows *in* through the board. This is called an *in* current. It is thus named so that it can be more easily indicated on a drawing. Now, if you will again make your contact and place the compass on the board in the positions indicated in Fig. 3, you will find that the darker end of the compass needle will align itself as shown in this sketch. That is, it will point in a clockwise direction (the direction in which the hands of a clock rotate) around this current-carrying rod.

The Magnetic Compass. Since a magnetic compass is simply a bar magnet of rather feeble strength, it is quite likely to become *reversed* if it is brought suddenly into the field of a magnet which is much stronger than the earth's magnetic field. If your compass is reversed, you will find that the darker end of the needle will point south instead of north. Naturally, if you use it in this condition, your results will be misleading. A compass is likely to become reversed if it is held in a position where the needle cannot make a quick swing on its pivot. When this happens, the field of the strong magnet remagnetizes the needle so that its lighter-colored end will point north. This may be remedied by holding it in this stronger field with the needle cramped or locked so that it will not turn upon its pivot while it is being remagnetized. You may do this as often as you like without injury to the needle. The question will now arise as to how you may know when the needle is pointing in the proper direction. This is simple enough. Just hold the compass in a position in which you are sure it is not being acted upon by strong magnetic fields, and that it is not too close to objects made

of iron, and observe the compass needle. If the dark end points in the general direction of the earth's north, then it is correct. If, however, the light-colored end points north, then the compass must be reversed before it can be used intelligently.

It is a law of magnetism that *like poles* of magnets *repel* each other, and *unlike poles attract.* You may ask then why the dark end of the compass, or *north pole* of this magnet, which is our compass needle, is attracted, or points, to the north pole of the earth. Perhaps it can be explained in this way—an explanation given by many of our scientists. Fig. 4 shows the magnetic lines or magnetic

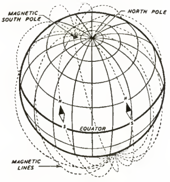


Fig. 4. Showing Magnetic Lines of Force Around the Earth

field about the earth. From this you will see that the earth itself is a great magnet. Its upper magnetic pole, however, does not coincide exactly with the north geographic pole of the earth, but it is located off to one side in the Peninsula of Boothia in Northern Canada. Hence, magnetic compass needles do not point to the exact geographic *north.* Since you know that like magnetic poles *repel* and unlike poles *attract,* you now know that the dark, or *north* end of the compass needle cannot point to another *north* pole. Thus, it now generally is conceded that the lines of force centering around this magnetic pole in the Peninsula of Boothia must constitute the *south* magnetic pole of the earth, somewhat adjacent to the earth's *north* geographic pole.

An understanding of the above discussion is absolutely necessary if you are to understand the compass action, keep your com-

pass correctly magnetized, and obtain correct readings with it. A compass that is not accurate will confuse you so that you will never get a complete understanding of magnetic action. Fig. 5 will help you to understand how a compass needle lines itself up in any other magnetic field.

Now, back to the experiment. With this understanding of the compass, you will know that the north, or dark, end of the compass needle will point to the south pole of a magnetic field, or in the direction in which the magnetic lines are flowing, since they *always*

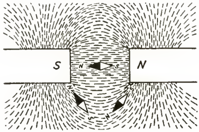


Fig. 5. The Compass Aligns Itself with Magnetic Lines

flow from north to south. In a circular field you will not have established poles, but the lines of force will flow from north to south, and the compass needle will point with them in their flowing. A compass needle placed upon the filings board will have the dark end of the needle pointing in a clockwise direction around this rod, with the current flowing *in* toward the board. This, then, is in keeping with the rule for finding the direction of a magnetic field about a wire carrying a current.

Right-Hand Rule for Finding the Direction of the Magnetic Field about a Wire.

Grasp the wire with the right hand, with the thumb extended along the wire and pointing in the same direction as the current; the fingers will then point in the direction with the encircling lines of force which form the field.

In the experiment which you have just performed, you had the direction of the current and have found the direction of the lines of force with the aid of the compass. You see that the result of the experiment conforms to the rule. Fig. 6 illustrates this rule, with the right hand applied to a conductor.

You can use this rule to find the direction of any direct current in any conductor. Simply place a compass either above or below the conductor, and note the needle direction. Then, if the fingers are placed in the direction shown by the compass needle, the extended right-hand thumb will indicate the direction of the current. Hold the conductor you are testing in a north-south direction, so that you can observe the slightest deflection of the needle from its normal position.

In Fig. 7 are shown magnetic fields about two wires. The one shown at A has the current flowing *in* and has a clockwise magnetic

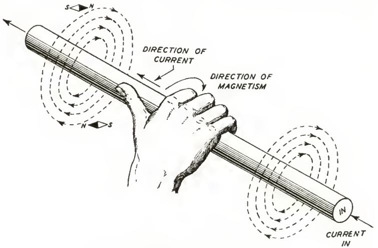


Fig. 6. Application of the Right-Hand Rule

field about it; the one shown at B has the current flowing *out* and has a counter-clockwise field about it.

You must remember that when one point or plane was chosen to show the magnetic field about a wire or cable, the field was shown at that point only, and that every point on the wire has a similar field encircling it. Naturally, these fields are relatively weak. You produced a strong field with the battery by allowing much more than normal current to flow through this wire. It is not practicable, ordinarily, to use such heavy currents. The proper way to get stronger action with a suitable current value is to group wires together, so that you can use the magnetic fields of all of them. To do this, you wind insulated magnet wire in the form of coils.

MAGNETIC FIELDS ABOUT COILS

Provide yourself with some insulated magnet wire. The bell wire sold in 10-cent stores will do. It would be better, however, if you could acquire some regular magnet wire in any gauge from No. 24 AWG (American Wire Gauge) to No. 20 AWG. Construct a large flat coil from this wire by winding it on a form that has about a 6-inch diameter. Put on about a hundred turns. The more turns, within reason, the less current the coil will draw. Tape this coil, or tie it with twine in several places, so as to preserve its shape. Then remove it from the winding form. Use a board similar to

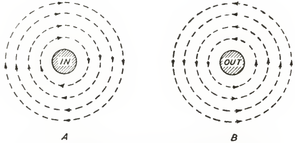


Fig. 7. Direction of Fields Around Wires Carrying Currents

the one used in the previous experiment, as shown in Fig. 3. Cut and notch it so that it will support the coil, as shown in Fig. 8. Large paper clips will serve to hold the two parts of the board together. When you have this set up, and have put the paper in place, sprinkle iron filings on the paper under the coil. Now make your battery connections so that the current will flow through the coil, in the manner indicated in Fig. 8. The filings should arrange themselves much more readily about this coil than they did about the rod of the first experiment. With the compass, determine the polarity of the coil and mark this on the paper. You will find that the Right-Hand Rule for Coils applies here.

Right-Hand Rule for Coils. *Grasp the coil with the right hand so that the fingers point around the coil and in the direction with the current; the thumb when extended will point in the direction of the north pole of the magnet.*

As in the other experiment, you can use the compass to deter-

mine the polarity of any coil, and the above rule to find the direction in which the current is flowing around it.

Experiment in Magnetic Field About a Coil. In Fig. 9 is shown a coil which has been cut through its length and the front half removed. This leaves the back half of the coil with the exposed wire ends visible. You will remember that the current flowed over the top of the coil, Fig. 8, to the rear. In Fig. 9 there are shown *in* cur-

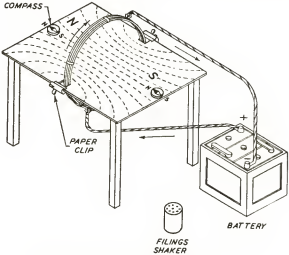


Fig. 8. Filings' Test Showing the Field through a Coil

rents through every wire on the top of this coil, and *out* currents through every wire on the bottom of the coil.

Now, around these top wires which have an *in* current you will have clockwise magnetic fields, and around the bottom wires which have *out* currents you will have counter-clockwise magnetic fields. Take one more look at Fig. 7, and compare the fields of Fig. 9 with the two shown in Fig. 7. Since the wires lie very close to each other in a coil, these fields about the individual wires tend to combine, and in so combining they are carried around so that they thread the entire coil. Note particularly that the lines of force which lie inside the coil, at top and bottom, are all traveling in the same direction. A reference to the filings' test that you have just made will bear this out. The field about this magnet is similar to the field about

a permanent bar magnet, but it is very much stronger in its magnetic action. It is, in fact, the best magnet.

Magnetic Effects of Iron Cores. Iron materials have great ability to gather and convey lines of force. It has been estimated that iron will gather and convey as high as 1000 to 1500 times the lines of force that can be conveyed in air. This ability to convey lines of force is known as *permeability*. It follows then that iron has a permeability of 1000 to 1500 times that of air. Therefore the magnetic strength of coils can be increased by supplying them with cores of iron.

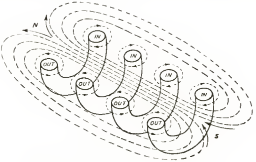


Fig. 9. Explanation of the Field Around a Coil

GENERATION OF CURRENT

From the two experiments just performed, you have seen that magnetic fields actually do lie about wires carrying currents. Here you have produced magnetic fields by supplying current to wires and to coils. In your next experiment, you will produce the current by supplying magnetic fields to the conductors.

Making a Current Detector. You must have some instrument by which to detect the presence of electricity, so that you actually can see when you have generated a current. By far the best instrument would be a laboratory galvanometer, or current detector, as this will indicate the presence even of a rather weak current. You know that the current you are about to generate will be weak, for you are going to use the simplest form of current generation. However, you can construct, with little effort, an instrument that will detect the presence of current. If you will wind a coil, having an

internal diameter of about 4 inches, Fig. 10, in the same manner in which you constructed the other coil, Fig. 8, using at least 200 turns of magnet wire, it will suffice for the coil part of this current detector. It should be mounted on the same kind of a board as that on which the former coil was mounted, and in the same manner. Instead of using filings on this board, however, you will place your compass on it, exactly under the coil, Fig. 10. It is better to use this instrument when the coil and compass needle are in an exact north-south direction, for that is the normal or *zero* position for the indicating compass needle. When the instrument is in this position, you can observe more readily any needle deflection that occurs.

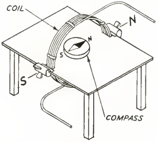


Fig. 10. Construction of Current Indicator

Experiment in Generating Current. The only other equipment needed for this experiment is a horseshoe magnet. If possible, get one from a telephone ringer magneto, or from the flywheel magneto of an old Model T Ford. You can buy one from the 10-cent store, but either one of the former would be larger and better. If your first coil will slip over one pole of the horseshoe magnet you have procured, you may use it in this experiment, provided it is wound with several hundred turns of wire. Connect the leads of this generating coil to the leads of the coil of our indicating instrument, Fig. 11. You do not use the battery in this experiment. You use only the generating coil, the horseshoe magnet, and the current indicator. You are now ready to generate electricity with the apparatus set up.

Take the horseshoe magnet in one hand and the free, or generating coil in the other. Stand in a position where you will be able to observe the slightest deflection of the compass needle. Now, quickly move the generating coil down over one pole of the horse-

shoe magnet. As this is moveu, and only while movement is occurring, you will note a deflection of the compass needle. A quick downward movement of the coil should cause the compass needle of your current-detecting instrument to be deflected in one direction. A quick withdrawal of this coil up from the field of the horseshoe magnet should show a deflection of the compass needle in the opposite direction. When there is no movement of the coil, there is no movement in the compass needle. Now carefully note the following facts:

1. Movement down over the pole of the magnet causes needle deflection in one direction.

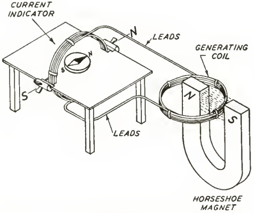


Fig. 11. Diagram Showing Generating Coil, Leads of Coil, and Indicating Instrument

2. Movement up over the pole causes needle deflection in the other direction.

3. Deflection of the needle ceases, and the needle returns to its normal or zero position, when coil motion ceases.

4. The faster the movement of the coil, or the cutting across the lines of force by the coil, the greater the deflection of the compass needle.

5. A small amount of needle deflection occurs when the coil is moved in a straight line, with the field, from one pole of the magnet to the other pole.

Note also that in this simple experiment you have not only produced a current, as indicated by the needle of the current-

detecting instrument, but that this current has been *used* to move this needle. In using it for this purpose, you have used a magnet acting on a coil, and in reading the effect of this generation of current, you have used a coil acting upon a magnet, which is the compass needle. In producing this power, you have used the motor action. Note that these two effects are closely related to each other.

What is Needed to Produce Current. In the generation of this current, you have used a *magnetic field*, supplied by the horseshoe magnet, a *conductor*, supplied by the generating coil, and *movement*,

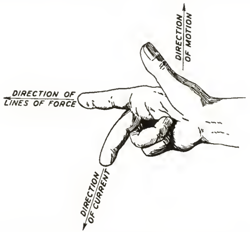


Fig. 12. Application of Fleming's Right-Hand Rule for Generators

supplied by your hand. These three factors of current generation are all that is necessary in any dynamo or generator. All three must be incorporated into a machine that generates current. Let us name them again: *field, conductor,* and *movement,* or motion.

The difference between a motor and a generator is that you *drive,* or *supply movement* to a generator, and take *current* from it, whereas in a motor you *supply the current* and take *power* from it.

By means of the simple generator, then, you have produced a small amount of current. You saw that with the apparatus you could generate current in two directions, since you observed that the needle was deflected first one way and then the other. The direction of a generated current can be determined by rule.

Fleming's Right-Hand Rule for Generators. *Extend the thumb,*

forefinger, and middle finger of the right hand, as shown in Fig. 12, *so that they are at right angles to each other. Place the forefinger in the direction of the magnetic field* (toward the south pole of the field) *with the thumb in the direction of the motion; then the middle finger,* Fig. 13, *placed along the conductor, will indicate the direction the current will take through the conductor.*

In Fig. 13, the direction in the magnetic field is from right to left, the movement being up, the current must then come out of the conductor.

If the conductor was moved from one pole to the other, or *with*

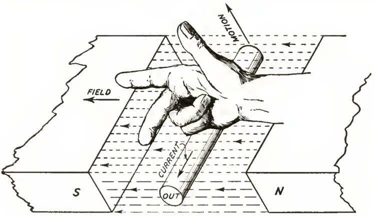


Fig. 13. The Application of the Right-Hand Rule for a Generated Current

the lines of force, very little current would be generated. To get the greatest generating effect, the conductor must be moved directly *across* the lines of force, or at right angles to them.

The Motor Effect. If, on the other hand, you placed this wire in the magnetic field and supplied it with a current, you would get action as shown in Fig. 14. Here the conductor carries a current; therefore it has a magnetic field about it, as shown at A in Fig. 7. This field about the wire will combine with the magnetic field illustrated in Fig. 5, in which it lies, and in so combining, the lines will follow each other around until more of them are gathered above the conductor than beneath it, as in Fig. 14. There is a natural tendency for lines of force *to shorten their paths,* once they have been set up, in much the same way that stretched rubber bands tend to straighten.

To make this clear, let us consider the dotted lines in Fig. 14, which really represent lines of force, as rubber bands between the two poles which have been stretched, or deflected, upward. It will be clear, then, that the tendency of these rubber bands to straighten would

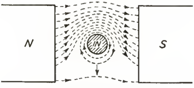


Fig. 14. The Expulsion of a Wire Carrying a Current from a Magnetic Field

tend to force the conductor down and entirely out of the magnetic field. This is the *motor effect;* and it is also the action of the direct-current motor.

Fig. 15 shows a simple wire-loop armature, so placed in a magnetic field that the combining of the field about the armature con-

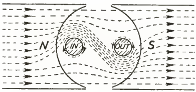


Fig. 15. A Wire Loop Carrying Current in a Magnetic Field Tends to Rotate

ductors and the parallel field will produce a counter-clockwise motion in the armature and cause it to turn. Direction of motion in a motor can also be found by the following rule:

Fleming's Left-Hand Rule for Motors. An electric motor performs the reverse function of a generator, in that it changes electricity into mechanical power. For generators the Right-Hand Rule is used to determine the direction of current, Fig. 12. A motor being the reverse of a generator, the Left-Hand Rule is used to determine direction, as shown in Fig. 16. *Extend the thumb, forefinger, and middle finger of the left hand at right angles to each other. Place the forefinger in the direction of the magnetic field, with the middle finger in the direction of the current in the conductor; the thumb will then indicate the direction of motion.*

When you know the direction of any two of the following: *motion, magnetic field* or *current,* you can determine the direction of the third by the use of this rule.

Power Required to Drive a Generator. It takes power to drive a generator, not only to overcome the friction of the bearings and the brushes which serve to carry off the generated current, but also to

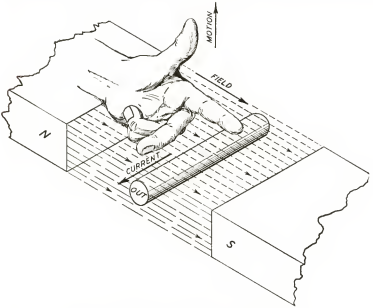


Fig. 16. Application of the Left-Hand Motor Rule

overcome a certain counter or back pressure which is built up in all generators.

Even though a generator is generating its own current, this current will still be flowing through its own windings, and in so doing it will supply to the generator all the necessary factors to create a motor. It will have a *magnetic field, motion* or movement, and its own current will be flowing through its windings. This will produce the *motor effect,* and power will result. Moreover, this power will be exerted as a force against the power that is driving the generator, in full accord with a law of physics.

Counter-Electromotive Force. Similarly, direct-current motors also act as generators, since motors fulfill all the requirements for

the *generating effect.* In this case the current will flow out against the current that is being used to run the motor. This current that is generated in a motor is called the *counter-electromotive force.* It is usually written *counter-e.m.f.* The term *e.m.f.* is used to indicate electrical pressure. It is possible to have electrical pressure in a wire, even though there is no current flowing through it. This will occur when a switch is open, or whenever the circuit is not completed. Sometimes, in these cases, the term *e.m.f.* is used to denote the presence of pressure when the value of that pressure in terms of voltage units is not known. The term *e.m.f.* also may be used with a pressure of a known voltage, as, an *e.m.f. of 12 volts.*

Volts as Units of Electrical Pressure. You might say that a generator produces a certain electrical pressure, or e.m.f., but in doing so you are not giving it an actual value for its electrical pressure. That value should be stated in *volts,* wherever possible, as volts are the units of electrical pressure.

You noticed in Fig. 11 that the deflection of the compass needle was dependent upon the following two things: first, the number of lines of force through which the conductor cut, and second, the time it took, or the rate of speed used, in cutting through them. Now magnetic lines of force are tiny things of themselves, and it takes many, many thousands of them to produce even slight results. In fact, it takes so many of them that *a single conductor has to cut through one-hundred-million of them in one second to produce an electrical pressure of one volt.* This, indeed, is the definition of a volt. *A volt equals 100,000,000 lines of force cut across in one second.* This, of course, is for a single conductor. A coil of two turns needs to cut but half as many to produce a volt. A coil of ten turns, needs to cut but one-tenth as many, and so on. A commercial armature has many turns in its windings, and many generators have two or more separate fields incorporated in their field frames. That is, they have four or six poles instead of two. All of this tends to reduce the speed at which the armature must be driven.

MUTUAL INDUCTANCE

You have proved that you can generate, or set up or induce a current in a conductor, if you can supply this conductor with a magnetic field and with movement. The conductor itself does not

have to be in actual physical motion. If the magnetic field is in motion, and cuts across the conductor, the results are the same.

Wind two coils as shown in Fig. 17, one hundred or so turns in each, designed so that one will readily fit into the other, with plenty of clearance between. Now, if you will arrange the connections as shown, you will have set up an apparatus illustrating clearly the fundamental principles of several important devices in modern electrical equipment.

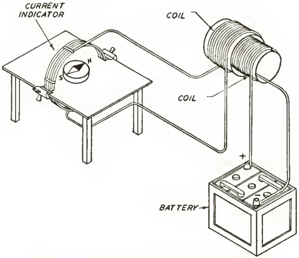


Fig. 17. Experiment Illustrating Action of Induction Coil

Experiment in Mutual Inductance. Having made your connections to the smaller, or primary coil, place the larger, or secondary coil, quickly over the first. As the coil comes into this position, the needle of the indicating instrument will swing sharply in one direction, returning immediately to its normal position. This shows that current is set up in the secondary coil only so long as physical motion or movement occurred. A quick removal of the coil will cause the needle to deflect in the opposite direction for a moment, and again come to rest in its normal position. You will note that current exists in the secondary coil only during the time that it is in motion. You will also note that movement of the coil into the field of the primary coil causes current to flow through it in one direction, while its move-

ment out of the field of the primary coil causes current to flow through it in the opposite direction. You then have a current that alternates first in one direction then in the other. In other words, you produced an alternating current from a direct current.

You will note also that when the secondary coil is in place, with current flowing through the primary coil, there is no action in the secondary coil (no current produced in it) unless *motion* of the coil occurs. You will conclude from this that *field motion* is necessary to produce a current.

Now, with current flowing through the primary coil and the secondary coil in place, move the primary coil in and out so that its field cuts across the windings of the secondary coil. In other words, move the primary coil instead of moving the secondary. You will find the action of the indicator needle to be the same as it was when the primary coil was at rest and the secondary coil was moved. Thus, you conclude that it makes no difference which coil is moved, just so the magnetic field is in motion, and that it is cutting across the conductors of the secondary coil. This conclusion is correct.

Now, with both coils in place, remove one battery connection to the primary coil. As this is being removed, you will see that the needle of the indicating instrument swings sharply in one direction. Replacing this connection will cause it to swing sharply in the other direction. Now *make* and *break* this connection several times. You will find that simply making and breaking the circuit will produce current in the secondary coil, just as it was produced when you moved either coil by hand.

This phenomenon is caused by the *expanding* and *collapsing* of the magnetic field about the primary coil. You will remember the expansion or spreading out of the tiny waves around the pebble which was tossed into the pool of clear water, Fig. 1. The waves spread out in ever widening circles from the point at which the pebble dropped into the water. Thus, the spreading of the magnetic field out from the primary coil, or from any other conductor which has just had a current set up in it, is similar. When the current is broken, or ceases to flow in a conductor, the field about that wire begins to collapse and the magnetic waves return quickly to the wire in the reverse of the action by which they were set in motion. So, in this experiment, you have a movement of the magnetic field

about the primary coil, that expands out across the windings of the secondary coil when the current is set up, and moves in across this coil when the circuit is broken. This is just as effective as if the coil was moved. Since the motion existed in the magnetic field itself, and the magnetic lines did their own cutting across the secondary coil, physical movement of the coil was not necessary.

Voltage Depends on Number of Windings, or Turns. If you will wind twice as many turns on the secondary coil, you will find the needle deflection to be twice as great. If half the turns are removed, the deflection of the needle will be only half as great.

This will indicate to you that there is a direct proportion in the voltage delivered by the secondary coil to the number by which its turns exceed those of the primary coil. With twice the number of turns on the secondary coil as on the primary coil, you will get twice the voltage from the secondary coil. With ten times more turns on the secondary coil, you would get ten times the voltage, and so on.

If you will now connect a door bell or a buzzer in series with the primary coil, you will add an automatic make-and-break device to the circuit, as the vibrator portion of the bell or buzzer will constantly *make* and *interrupt* the primary circuit. This will give you a continuous alternating current flowing from your secondary circuit. You will not be able to detect its presence with your indicating instrument, however, for the needle of the compass will be far too slow and sluggish to record such rapid changes. Nevertheless, the current is there.

Ignition Coils and Transformers. From the ideas embodied in this experiment, engineers have developed some of our most modern electrical devices. They have designed an iron core, consisting of a bundle of short lengths of iron wire. This core, made up of a group of individual wires or rods of high-grade iron, is for the purpose of minimizing or reducing the stray magnetic currents, called *eddy currents*, that would be harmful rather than helpful to the magnetic circuit. Around this bundle of iron wires, they have wound a primary coil suitable for a 6-volt current supply. Over this assembly, they have wound an extremely high-voltage secondary coil. Into the primary circuit, and actuated by the magnetism of the core, they have built in a vibrator, which is quite similar to that of the

electric bell or buzzer, to interrupt the primary circuit automatically. Across the points of this vibrator they have bridged a *condenser*.

This condenser is for the purpose of reducing any sparking or arcing which might occur, and also to aid in the collapsing of the magnetic field about the primary coil when the circuit is broken by the interrupter. This device is variously known as a spark coil, an ignition coil or an induction coil. They put it to work, supplying its high-voltage to spark plugs of stationary and automotive engines. For many years this spark coil, as shown in Fig. 18, was used on all automobiles. You may remember its use on the Model T Ford. It

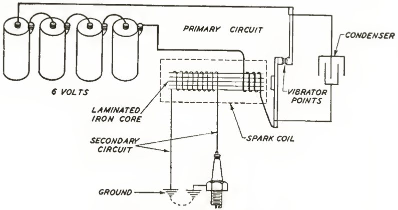


Fig. 18. The Vibrating Ignition Coil

is used still in the ignition systems of many stationary gasoline engines.

When the automobile was finally refined by precision designing to a point where a *shower* of sparks was not needed in the firing of its cylinders, the vibrator of this coil was discarded, and its place was taken by the highly accurate *interrupter* or *breaker*. This device is now located in the distributor head of the ignition system which supplies the high tension voltage to the spark plugs of the modern automobile. Fig. 19 shows this coil and its breaker. This breaker produces but one *break*, instead of a *shower of sparks*, and produces it at the *exact* time needed for firing the cylinders. However, the coil is basically the same. The same fundamental ideas are incorporated in it as were used in the experiment shown in Fig. 17.

Perhaps a brief word should be said about the condenser which has been added to the above coil. A condenser might be considered as a *storage place* for electricity. It holds a *charge* of electricity, which it can be made to discharge at a given time with a rush like a lightning flash. Since it does not retain charges over long periods, it must be discharged shortly after it is charged, if you are to derive the full benefit of the electrical energy. In its position in the circuit described—bridged across (or in parallel with) the points of the breaker—it receives its charge when the circuit is *made* and discharges it when the circuit is *broken,* or interrupted. This discharge sends

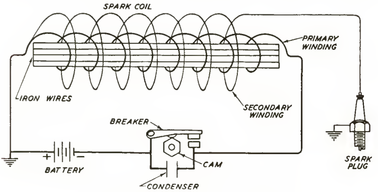


Fig. 19. Ignition Coil with Breaker or Interrupter

a rush of electricity back through the primary coil, to aid the breaking down or collapsing of the magnetic field about the primary coil. This causes the collapsing lines of force to cut across the secondary windings much more rapidly than they would without the aid of the condenser, and a much higher voltage and hotter spark result. A defective, or broken down, condenser will put any coil out of commission, and it should be replaced by a new one.

This spark or ignition coil, which we just have described, is technically known as a *mutual-inductance coil.* It consists of two separate and independent windings with no electrical connection between the two windings, as shown in Fig. 18.

This mutual-inductance coil, when properly designed for the purpose, becomes the *electrical transformer* of the lighting and power lines. When it is supplied with an alternating current in its primary

coil, the alterations of the circuit take the place of the vibrator or breaker. With alternating current as a primary current source, the magnetic field of this coil is in constant motion. This field is constantly *expanding* and *collapsing* across the conductors of the secondary coil. Thus, *motion* of the field is obtained without any physical movement whatever. With the proper ratio in the number of turns of the primary and the secondary windings, the transformer will either *step up* voltage or it will *step* it *down*. It is the *step down* transformer which serves the residential districts with the proper voltage for lights and appliances, from the line which is carrying a higher distribution voltage.

SELF-INDUCTANCE

Mutual inductance coils are not the only ones used in the ignition systems of gasoline engines. Some gasoline engines of the stationary variety are equipped with *make-and-break* ignitors. These are supplied with current from *choke* or self-inductance coils. This coil consists of insulated wire wound around an iron core. It is, to all intents and purposes, the simple primary winding of an induction coil, with the secondary windings and the vibrator or breaker discarded. It operates on the principle of *self-inductance*. If you will refer again to Fig. 9, you will see that the field about any one turn of a coil will cut across the other conductors of the same coil as it *builds-up* and *collapses*. In doing this, a *current* is generated in each of these turns *even though these turns at the same time are carrying the current producing this magnetic field*. There is always self-induction, in any coil. The current formed by this self-induction is generated in such a manner that its direction *opposes* that of the current which sets it up. In other words, it is a counter-e.m.f.

When the circuit containing a self-inductance coil is *made*, very little spark is apparent. However, when the circuit is *broken*, or interrupted, the magnetic field about the many turns of the coil collapses. In doing this, *it produces a current that flows momentarily in the same direction as the original current* and greatly strengthens it.

Lenz's Law. This is in keeping with Lenz's Law of physics, which states, in part: *The induced e.m.f. tends to set up a current whose magnetic field always opposes any change in the existing field.* So, in this circuit when the current is interrupted, the magnetic field

of the self-induced current tends to oppose this change, or interruption, and both magnetic fields act together to set up a larger current than was present originally in the conductor. Thus, there is a very heavy current in the coil at the instant the circuit is broken. It will produce a large spark, ample to fire a mixture charge in a low-compression engine. The make-and-break ignition device located in the cylinder of the engine is mechanically operated from the engine itself, so that it occurs at the proper time to fire the mixture charge. The ignition device, the choke coil, and the battery are all connected in series. This is shown in the diagram, Fig. 20.

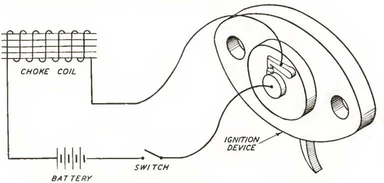


Fig. 20. Diagram Showing Ignition Device, Choke Coil, and Battery

COIL AND PLUNGER MAGNETS

Another type of magnetic action is the *coil and plunger* magnet. This is a solenoid, or coil, equipped with a solid iron core, or plunger, which is free to slide in its position within the coil. It is sometimes called a *sucking* coil, because of its interesting action.

If you can obtain a short length of brass or copper tubing and a rod of iron that will pass freely through this tube, you will benefit by constructing this magnet.

Wind several layers of insulated magnet wire around a 6-inch length of this tubing, leaving exposed a sufficient length of the wire to allow for battery connections.

Having made these connections to the battery, slowly insert the iron rod, which you are to use for the core, into the tube. You will notice a decided *pull.* It is quite possible that this pull will be sufficient to jerk the rod from your hands. Through this experiment you

should get a clear idea of the comparison between the lines of force and stretched rubber bands; for an effort to withdraw the plunger from the magnet will convey the feeling of pulling against a rubber band, and release of the core when it is at the height of this feeling will cause the plunger to return to the magnet as if snapped back there by a released rubber band. This provides the best illustration of the rubber band effect.

The action of this coil, which is shown in Fig. 21, is simple. It is

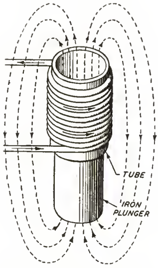


Fig. 21. The Solenoid with a Plunger

caused by the lines of force put out from the magnet and permeating the iron of the core. Once they are established in this core, they tend to shorten themselves. In so doing, they exert a force on the core, tending to pull it into the coil until the center of the core coincides with, or is at, the center of the magnet, when core movement ceases. It will then be held in that position. This action is the same when the core is withdrawn from either end of the coil. This is a useful type of magnet and one which has many practical industrial applications.

Indeed, all of the foregoing principles of induced currents are applied many times daily in various electrical controlling devices, so necessary to modern industry.

REVIEW QUESTIONS

1. What is the basic difference between a *motor* and a *generator?*

2. By what two means can we ascertain the presence of a *magnetic field* about a conductor?

3. What configuration does the field take and in what plane with respect to the wire?

4. Assume that a wire carrying current passes through the plane of this page at right angles and that the current is flowing downward. Draw a simple sketch to show the direction of the *magnetic field.*

5. Explain why the dark, or north, end of the magnetic compass points to what we call the *north pole.* How does this compare with the way in which the compass behaves when brought close to the *south pole* of a bar magnet? What conclusion can you draw from this observation?

6. State the right-hand rule for finding the direction of the *magnetic field* about a wire. (It is a good idea to memorize this rule or, at least, fix the concept clearly in mind.)

7. State the right-hand rule for *coils.* (Another good rule to memorize.)

8. In what way is the field around a coil carrying current similar to the field around a magnet?

9. Why is the field around a coil stronger than the field around a single wire?

10. Name the three factors necessary for the generation of an electric current.

11. Give Fleming's right-hand rule for generators. (Memorize the principles of this rule.) Note the similarity between the three right-hand rules you have learned.

12. Explain the *motor effect.*

13. State Fleming's left-hand rule for motors. Why is the left hand used for motors instead of the right hand as for generators?

14. What is *counter-electromotive force?* In what direction will the current run with respect to the current supplied by a generator?

15. Define a *volt* in terms of lines of force cut and time.

16. In the experiment in Fig. 17 on page 255 what three means may be used to obtain relative movement of the magnetic field to produce an induced current and an indication on the current indicator?

17. In the same experiment why is deflection of the compass needle first in one direction, then in the other?

18. In a compound inductance coil composed of a *primary* and *secondary* coil, upon what two factors does the value of voltage induced in the secondary coil depend?

19. In the experiment described in Fig. 17 on page 255 would there be any indication on the current indicator when there is no relative movement of the primary and secondary coils?

20. Compare briefly the action of a Model T Ford spark coil with that of the modern ignition coil.

21. In what manner is *relative field motion* obtained in the ordinary transformer?

22. What is *self-inductance?*

23. State Lenz's law.
24. What is the effect of an iron core in an electromagnet?
25. Describe briefly the action of a *solenoid.*

APPLICATIONS TO INDUSTRY

1. What is the purpose of the condenser connected across the breaker points of an ignition coil?

2. What is meant by a *step-up* or *step-down* transformer? What is the ratio of primary to secondary *windings* and primary to secondary *voltages* in either case?

3. In terms of the definition of a volt as given on page 254, would a higher voltage be generated in the experiment in Fig. 11 on page 249 with a slow or a fast movement of the coil over the leg of the magnet?

4. What is the purpose of a *breaker* or interrupter on an ignition coil?

5. A magnetic compass placed above a rubber-covered wire carrying a direct current has the north end deflected to the left. Is the current flowing toward you or away from you?

6. If you had a transformer from which you wished to obtain a higher secondary voltage, what would you do without increasing the primary voltage?

7. What would be the result of a "shorted" condenser across the breaker points of an automobile ignition system?

PRINCIPLES OF A GENERATOR

INTRODUCTION

Essential Parts of a Dynamo. The dynamo is a machine for converting mechanical energy into electrical energy or electrical energy into mechanical energy. When it is used in transforming mechanical into electrical energy, it is called a generator; and when it transforms electrical into mechanical energy, it is called a motor. The great majority of dynamos have the following essential parts: the magnetic field; the armature winding; the commutating and collecting devices (not required in all machines —the squirrel-cage induction motor, for example); and the necessary mechanical structure, such as bed plate, iron composing the magnetic circuit and its supporting structure, armature core, bearing supports, etc.

Magnetic Field. The function of the magnetic field is to provide a magnetic flux, which is cut by the inductors forming the armature winding.

Armature Winding. The armature winding is composed of a large number of wires, called inductors, in which an electromotive force (e.m.f.) or electrical pressure is induced when there is a relative movement of these inductors with reference to the magnetic field of the machine.

Commutator or Collecting Rings. The function of the commutating and collecting devices is to bring about the necessary reversal of connections between the various elements composing the armature winding and the external circuit, and at the same time to provide the necessary continuous electrical connection between the circuits on the moving part of the machine and the outside circuits.

Mechanical Parts. The function of the various mechanical parts is obvious, and the iron composing the magnetic circuit often performs a mechanical function in the construction of the machine, as, for example, the iron used in the construction of

the armature core serves as a mechanical support for the armature windings.

In commercial continuous-current machines, the field magnet is nothing more than a simple electromagnet which remains stationary, but the armature is a great deal more complex and always rotates. In alternating-current machines either the armature or field may be stationary. Continuous-current machines always require a commutator, which is mounted on the same shaft as the armature, while the alternating-current machines are provided with slip rings when an electrical connection must be established between the rotating part of the machine and an outside circuit.

The development of the various forms of armature windings for both continuous- and alternating-current machines will be discussed in the following sections.

Producing an E.M.F. by Cutting Magnetic Lines of Force. When a conductor and a magnetic field are caused to move relative to each other, so that the imaginary lines of force that are supposed to compose the magnetic field are cut by the conductor, there will be an e.m.f. induced in the conductor.

E.M.F. Depends on Rate Lines Are Cut. The value of this induced e.m.f. at any instant will depend upon the rapidity with which the lines of force are being cut by the conductor at that particular instant. If the lines of force are being cut at a perfectly uniform rate, that is, if the same number are cut in each succeeding fractional part of a second, say one hundredth part of a second, and there is a total of 100,000,000 lines cut in one second, then there will be an e.m.f. of one volt induced in the conductor. Thus if a horizontal conductor 50 inches long were moved downward across a horizontal magnetic field whose intensity is 20,000 lines of force as indicated in Fig. 1, at a uniform velocity of 10 inches each second, all the magnetic lines in the area 10×50 inches would be cut in one second. Since there are 20,000 magnetic lines passing through each unit of area, then the total number of magnetic lines cut by the conductor in one second will be equal to $10\times50\times20000$, or 10,000,000. Dividing 10,000,000 by 100,000,000 gives 0.1 volt, the value of the e.m.f. induced in the conductor.

If the conductor be moved at a greater velocity, say twice as fast, then the e.m.f. induced will be equal to twice the stated value, and if its velocity be decreased there will be a corresponding decrease in the induced e.m.f. If the strength of the magnetic field be increased or decreased in value, there will be a corresponding increase or decrease in the value of the induced e.m.f. Likewise, if the length of the conductor in the magnetic field, or that part of the conductor which is actually cutting lines of force, be increased or decreased, there will be a corresponding increase or decrease in the value of the induced e.m.f.

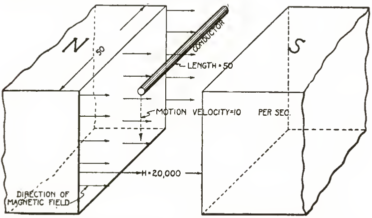


Fig. 1. Horizontal Conductor Moving Downward across a Uniform Magnetic Field—Motion Perpendicular to Field

If this conductor be made to form part of a closed electrical circuit, there will be a current of electricity produced in the circuit due to the e.m.f. induced in the conductor.

Right-Hand Rule. There is a definite relation between the direction of the magnetic field, the direction of motion of the conductor, and the direction of the induced e.m.f., which is as follows: If the first and second fingers and the thumb of the right hand be placed at right angles to each other and in such a position that the first finger points in the direction of the magnetic field and the thumb points in the direction of motion, then the second finger will point along the conductor in the direction of the induced e.m.f. The direction of the induced e.m.f. will be reversed if the direction of the motion or the direction of

the magnetic field be reversed. If the direction of the magnetic field and the motion both be reversed, then the direction of the induced e.m.f. will remain the same.

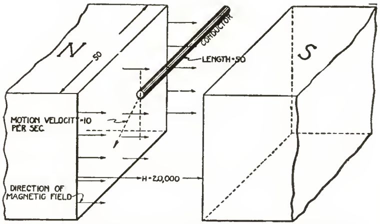


Fig. 2. Horizontal Conductor Moving Downward across Uniform Magnetic Field—Motion Not Perpendicular to Field

The motion of the conductor in Fig. 1 is perpendicular to the direction of the magnetic field, and, as a result, more magnetic lines are cut by the conductor when it moves a certain distance along its path than would be cut if the motion of the conductor were along a path making an angle of less than 90° with the direction of the magnetic field, Fig. 2.

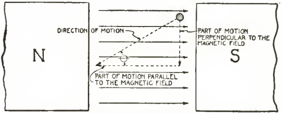


Fig. 3. Motion of Conductor Resolved into Two Components—One Perpendicular to Field and One Parallel to Field

In Fig. 2 it is that part of the velocity of the conductor perpendicular to the direction of the magnetic field that determines the rate of cutting of the magnetic lines. This part of the velocity of the con-

ductor is indicated by a dotted vertical line downward from the conductor, Fig. 2. It is also illustrated in Fig. 3 where the diagonal line "direction of motion" is divided up into "part of motion perpendicular to the magnetic field" and "part of motion parallel to the magnetic field."

When the angle between the direction of motion of the conductor and the magnetic field is 30° as in Fig. 3, that "part of the motion perpendicular to the magnetic field" is only one-half of the "direction of motion." This can be verified by measuring the two dotted lines in Fig. 3. A change in the angle θ from 30° to 45° or 60° will cause a greater part of the "direction of motion" to be "perpendicular to the magnetic field." When this angle θ becomes 90°, all the "direction of motion" will be "perpendicular to the magnetic field." Thus that part of the motion that is perpendicular to the magnetic field has to be determined before the voltage can be determined.

SIMPLE GENERATOR

Analysis of Operation. *Straight Conductor.* When the conductor, Fig. 1, has moved downward a sufficient distance to be

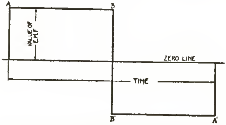


Fig. 4. Curve Representing Variation in Value of Electromotive Force Induced in a Conductor That Is Moved Back and Forth across a Uniform Magnetic Field at a Constant Velocity

out of the magnetic field, there will be no e.m.f. induced in it, as it continues to move on down, for there will be no magnetic lines of force cut by the conductor. Now, in order that the conductor may continue cutting the magnetic lines of force, it will be necessary for the motion of the conductor to be reversed when it reaches the edge of the magnetic field in its downward travel; that is, the motion of the conductor must be alternately up and down across the magnetic field. If the strength of the magnetic field is uniform in the region in which

the conductor moves and the velocity of the conductor is constant and the direction of its motion is reversed instantly, then the variation in the e.m.f. induced in the conductor may be represented graphically as shown in Fig. 4. Assume that the conductor starts from its uppermost position in the magnetic field, as shown at *A*, Fig. 5, and moves at a constant velocity downward across the magnetic field to its lowermost position, as shown at *B*, Fig. 6. During this time the conductor is cutting the magnetic lines at a constant rate for all positions and, as a result, the e.m.f. induced in it is constant, as represented by the upper part of the line *AB*, Fig. 4. The height

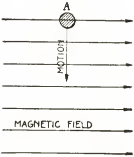


Fig. 5. Conductor Entering Magnetic Field and Moving Downward across Same

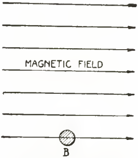


Fig. 6. Conductor at Lower Edge of Magnetic Field

of the horizontal line *AB* above the zero line is a measure of the e.m.f. induced in the conductor. Now when the conductor reaches the lowermost position, it immediately starts to move upward across the magnetic field at the same rate it was originally moving downward across the field, and, as a result, the value of the induced e.m.f. will be the same but its direction will be exactly opposite what it was originally. This fact is shown diagrammatically in Fig. 4 by the line *B'A'*, which is parallel to the zero line and exactly the same distance below the zero line as the line *AB* is above the zero line. The lengths of the lines *AB* and *B'A'* are drawn to represent time to any convenient scale; thus each inch may correspond to one second, etc.

Action of Loop. The arrangement just described may be greatly improved upon by revolving a loop of wire in a magnetic field, as shown in Fig. 7. Four positions of the loop are shown in cross-section in Fig. 8, and the e.m.f. induced in the loop for these different

positions may be determined as follows: In position *1* the plane of the loop is perpendicular to the direction of the magnetic field, and if the loop be rotated a small angle about its axis, there will be no e.m.f. induced in it because there are no magnetic lines cut by any part of the loop. The two sides of the loop will be moving parallel to the magnetic field, and hence cutting no lines of force; while the planes in which the two ends move are parallel to the direction of the magnetic field, and hence the ends will never cut across any of the

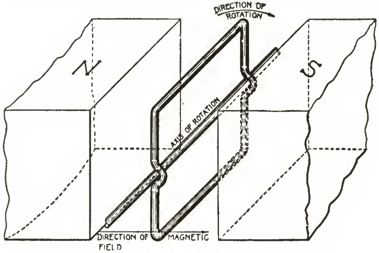


Fig. 7. Closed Loop of Wire Revolving in a Uniform Magnetic Field

lines of force forming the magnetic field, regardless of the angular position of the coil, so long as the axis of the loop is perpendicular to the direction of the magnetic field.

In position *2* the plane of the loop is parallel to the magnetic field and the two sides of the loop are moving perpendicular to the magnetic field for an instant while the loop is in this position. Since the sides of the loop are moving perpendicular to the direction of the magnetic field, when the loop is in position *2* they will be cutting the magnetic lines at the greatest possible rate.

In position *3* the plane of the loop is perpendicular to the direction of the magnetic field and the e.m.f. induced in the two sides is zero, for the same reasons as those given for position *1*. In position *4* the plane of the loop is parallel to the direction of

the magnetic field and the two sides are moving perpendicular to the direction of the magnetic field just as explained for position *2*. In position *2*, however, the side E is moving downward across the magnetic field and the side F is moving upward across the magnetic field, while in position *4* just the reverse is true; that is, side E is moving upward across the magnetic field, and side F is moving downward across the magnetic field. The e.m.f. induced in the two sides will be in opposite directions for all positions of

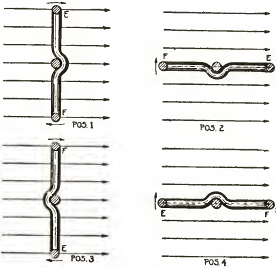


Fig. 8. Four Different Positions of a Loop as It Revolves in a Magnetic Field

the loop as you look along the two sides, but it will be observed that they are acting together around the loop rather than opposing each other, for all positions of the loop.

From position *1* to position *3*, the side E is moving downward across the magnetic field and the side F is moving upward across the field, while from position *3* back to position *1* the side E is moving upward across the magnetic field and the side F is moving downward. As a result of this relation between the direction of motion of the sides of the loop and the direction of the magnetic field, there will be an electrical pressure induced in the loop which will act around the loop in a certain direction while the loop is rotating from position *1* to position *3* and around the loop in the

opposite direction while rotating from position *3* to *4* and on back to position *1*, or the starting point.

Variations of E.M.F. in One Revolution. The value of the e.m.f. in the loop does not remain constant, but changes in value as the position of the loop in the magnetic field changes, the reason being that the velocity of the sides across the magnetic lines of force for a certain constant angular rotation of the loop is continuously varying in value. This can be proved easily by counting the number of fine lines the loop or conductor crosses in Fig. 9 when moving from

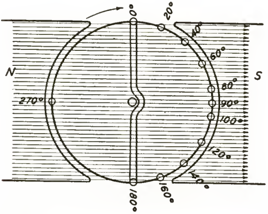


Fig. 9. Diagram Showing Variations in Number of Lines of Force Cut During a Revolution of an Armature Conductor

0° to 20° and comparing them with the number of lines crossed for similar distances in other parts of the revolution. They are as follows:

From 0° to 20° — 1 Line	From 100° to 120° — 6 Lines
From 20° to 40° — 4 Lines	From 120° to 140° — 5 Lines
From 40° to 60° — 5 Lines	From 140° to 160° — 4 Lines
From 60° to 80° — 6 Lines	From 160° to 180° — 1 Line
From 80° to 100° — 7 Lines	....

The number of lines crossed as the conductor or loop rotates from 180° through 270° to 360° is the same as 0° to 180°. You could make Fig. 9 very large in size and draw many fine lines and get more accurately the number of lines crossed in different parts of a revolution. In fact, you could determine the number of lines of force crossed

for each degree from 1° to 90°. However, this work is not necessary because the mathematicians have prepared tables that will give us these comparisons. They call these tables "sine of an angle" and use a symbol like this θ as an abbreviation to indicate the angle. These tables are often called *"Sine Tables"* and are given in all books on trigonometry. By using these sine tables you can easily determine what part of the maximum number of lines of force are being crossed at any particular angle.

Since the value of e.m.f. or voltage produced in the conductors depends upon the number of "lines of force" crossed, these sine tables will tell us what part of the maximum voltage is produced at any posi-

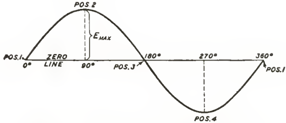


Fig. 10. Curve Representing Variation in Value of Electromotive Force Induced in a Loop That Is Rotated at a Uniform Angular Velocity in a Uniform Magnetic Field

tion of the conductors or loop. These values can be plotted as a curve, Fig. 10, in which the maximum voltage produced (abbreviated $E_{\max}$) in Position 2 of the loop, Fig. 8, is multiplied by the sine of the different number of degrees. This curve, Fig. 10, is called a sine curve because the height of the curve above the zero line at different places is obtained by the use of these sine tables. The distances along the zero line, Fig. 10, are divided into degrees from zero to 360°, but only 90°, 180°, 270°, and 360° are marked; these correspond to the position of the loop in Fig. 8. The distances along the zero line correspond to the values of the angle θ. Such a curve is called a sine curve.

Effect of More Loops. The e.m.f. may be increased by adding more turns to the loop and connecting these turns in series so that the e.m.f. induced in the different turns acts in the same direction around the loop.

The complete set of positive and negative values represented

in Fig. 10 constitutes what is called a cycle. A complete set of positive or negative values constitutes what is called an alternation. There are always twice as many alternations as there are cycles. The number of complete cycles that occur in one second is called the frequency. In Fig. 10 one revolution of the loop constitutes a cycle, or two alternations; and if the loop is made to revolve at the rate of 60 revolutions per second, the frequency of the induced e.m.f. will be 60 cycles.

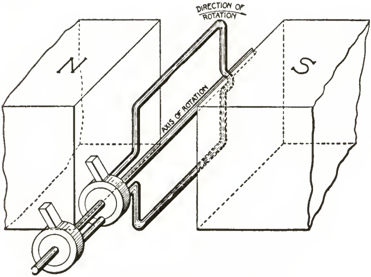


Fig. 11. Simple Alternating-Current Generator

Function of Slip Rings. In order to make use of the e.m.f. generated in the loop, Fig. 7, in producing a current in an electrical circuit, it is necessary to provide some means of connecting the loop in series with the circuit in which the current is to be produced. Such an electrical connection may be provided by opening up the loop and connecting the two ends thus formed to two continuous metal rings, mounted on the axis of the loop and insulated from each other. Upon these rings are two metal or carbon brushes, connected to the external circuit, as shown in Fig. 11. Such a device constitutes a simple alternating-current generator.

Function and Operation of Two-Part Commutator. As the loop of wire in Fig. 11 is made to revolve, an e.m.f. will be induced in

it, and this e.m.f. will reverse in direction twice every revolution, as shown by the curve in Fig. 10. If the external circuit be closed, the alternating e.m.f. induced in the loop will produce an alternating current in the circuit. Such a current is not suitable for all purposes, as, for example, charging storage batteries, and must be changed to a unidirectional or direct current. It is the function of the commutator to change the alternating current in the loop into a direct current in

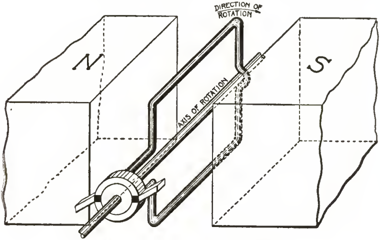


Fig. 12. Simple Direct-Current Generator

the external circuit and at the same time provide the necessary electrical connections between the loop and external circuit.

The simplest form of commutator consists of a metal ring divided into two equal parts and mounted on a tube of insulating material, the two halves of the ring being insulated from each other. Each half of the ring should be connected to one of the ends of wire formed by opening up the loop, Fig. 12. The metal parts composing the commutator are called segments. The two segments in the commutator are shown in Fig. 12. The electrical connection to the external circuit is made by means of suitable brushes which make electrical contact with the segments of the commutator. Two brushes are required with a two-part commutator and single loop, as shown in Fig. 12, and these brushes should be equally spaced on opposite sides of the commutator, and in such a

position that the insulation between the segments of the two-part commutator is exactly in the middle of the brushes when the plane of the loop is perpendicular to the direction of the magnetic field, or the induced e.m.f. in the loop is zero. A two-part commutator of this kind will reverse the connections of the loop of wire with respect to the external electrical circuit when the e.m.f. in the loop is zero and the e.m.f. acting on the external circuit always will be in the same direction and may be represented graphically by a curve such as the one shown in Fig. 13. This kind of an e.m.f. is called a pulsating e.m.f. because it pulsates in value at regular intervals; it is, however, continuous in direction. In order to produce an e.m.f.

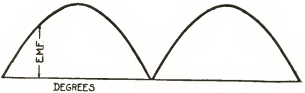


Fig. 13. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 12

nearer constant in value more commutator segments and loops of wire must be used.

Operation of Four-Part Commutator and Two Loops of Wire. The fluctuation in the value of the e.m.f. between the brushes with the arrangements shown in Fig. 12, can be reduced by using two more commutator segments and a second loop. In this case the metal ring is cut in four parts instead of two, thus forming a commutator composed of four segments instead of two. The two loops are placed at right angles to each other and the terminals of each loop are connected to commutator segments that are opposite to each other instead of adjacent to each other. The connections of the loops and segments are shown in Fig. 14. Two brushes are required, and they should be placed exactly opposite each other and in such a position around the commutator that they pass from one segment to the next when the planes of the two loops are making angles of 45 degrees with a plane perpendicular to the direction of the magnetic field. The proper position of the brushes is shown in Fig. 14. Let us now consider the operation of this machine.

Starting with loop *A* parallel to the magnetic field, loop *B*, which is at right angles to loop *A*, will be perpendicular to the direction of the magnetic field. When the loops are in this position the brushes should be in the center of the segments connected to loop *A*. Now as the combination of loops and commutator (called the armature) rotates, the e.m.f. induced in loop *A* decreases in value and the e.m.f. induced in loop *B* increases in value (it is to be remembered at the start the e.m.f. in *A* is at its maximum value and the

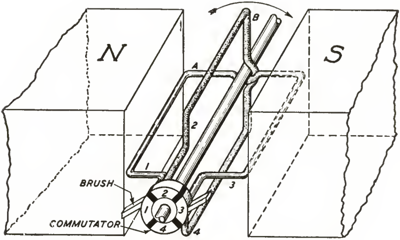


Fig. 14 Direct-Current Generator Composed of Two Loops of Wire and a Commutator of Four Segments

e.m.f. in *B* is zero). When the armature has turned through an angle of 45 degrees, the commutator segments connected to loop *A* move from under the brushes and the commutator segments connected to loop *B* move under the brushes. This results in loop *B* now being connected in series with the external circuit instead of loop *A*. Loop *B* will remain in electrical connection with the external circuit for the next 90 degrees' rotation of the armature, or one quarter turn, when the segments connected to *B* move from under the brushes and those connected to *A* move under the brushes. From the above statements and a careful inspection of Fig. 14 it is apparent that the loops *A* and *B* are alternately connected to the external circuit, and each time either of them is connected it is for one quarter of a revolution of the

armature. The e.m.f. between the brushes varies in value, but it will never drop to zero value as with the single loop. The connections of the loops are changed when they are making an angle of 45 degrees with a plane perpendicular to the direction of the magnetic field and the e.m.f.'s induced in the loops at this instant are equal in value and equal to 0.707 of the maximum e.m.f. induced in either loop when its plane is parallel to the direction of the magnetic field. This results in the e.m.f. between the brushes fluctuating in value between a maximum value and 0.707 of this maximum value. The fluctuation in e.m.f. for one complete revolution of the armature is shown in Fig. 15.

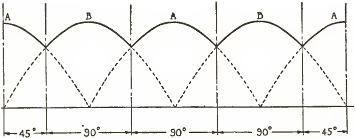


Fig. 15. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 14

Operation of Six-Part Commutator and Three Loops of Wire. The fluctuation in the value of the e.m.f. between the brushes with the arrangement described in the preceding section may be decreased by using three loops of wire and a commutator composed of six segments. The terminals of each loop should be connected to two segments exactly opposite each other and the brushes should be exactly opposite each other and in such a position that they are in the center of the commutator segments connected to a loop when that loop is in a position parallel to the direction of the magnetic field, or when the e.m.f. induced in the loop is at its maximum value. The arrangement of the loops, brushes, and commutator segments is shown in Fig. 16. Now as the armature rotates, the e.m.f. induced in loop A decreases in value, the e.m.f. induced in B decreases in value, and the e.m.f. induced in C increases in value. When the armature has turned through an angle of 30 degrees the segments connected to the loop A move from under the brushes, and the segments con-

nected to loop C come into contact with the brushes and remain in contact for a rotation of the armature of 60 degrees, or one-sixth revolution. When the segments connected to loop C leave contact with the brushes, the segments connected to loop B make contact, and remain in contact for one-sixth revolution, then loop A comes into contact again for one-sixth revolution; then loop C for one-sixth revolution, loop B for one-sixth revolution, and back to loop A for an angular movement of 30 degrees. This brings the armature back to

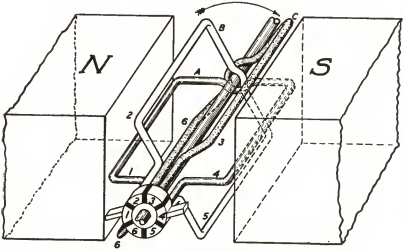


Fig. 16. Direct-Current Generator Composed of Three Loops of Wire and a Commutator of Six Segments

the starting point. The fluctuation in e.m.f. for one complete revolution of the armature is shown in Fig. 17.

Operation of Two-Part Commutator and Two Loops of Wire. Two loops of wire may be connected in parallel between two commutator segments as shown in Fig. 18. The e.m.f. between the brushes will be the same as though a single loop of wire were used, but the current the armature is capable of delivering will be doubled if the wire used in winding the loops is of the same size as that used in winding the single loop. The variation in the e.m.f. between the brushes for such a combination is shown in Fig. 13.

Operation of Four-Part Commutator and Four Loops of Wire. An armature may be formed by interconnecting four loops of wire

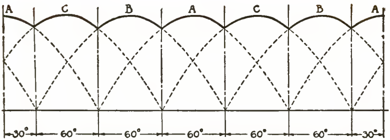


Fig. 17. Curve Representing Variation in Value of Electromotive F^rce between Brushes of Direct-Current Generator Shown in Fig. 16

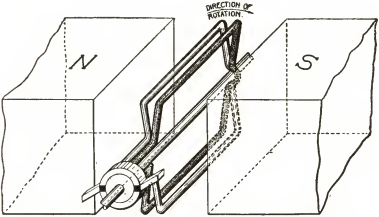


Fig. 18. Direct-Current Generator Composed of Two Loops of Wire and a Commutator of Two Segments

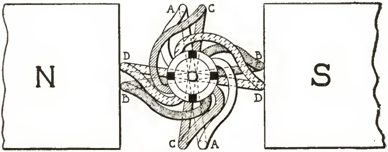


Fig. 19. Direct-Current Generator Composed of Four Loops of Wire and a Commutator of Four Segments

and four commutator segments. The connections are shown in Fig. 19. Each loop has its terminals connected to adjacent commutator segments. The brushes must be broad enough to bridge the insulation between adjacent segments, and they are mounted on the commutator in such a position that they short-circuit the loops when the sides of the loops are moving parallel to the magnetic field.

An inspection of Fig. 19 will assist you in understanding the following statements. When the armature is in the position shown in Fig. 19, the e.m.f. induced in the loops A and C is zero, and the e.m.f. induced in the loops B and D is a maximum. Of course, loops A and C are short-circuited by the brushes, but no damage re-

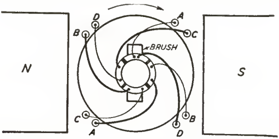


Fig. 20. Position of Conductors and Brushes after the Armature in Fig. 19 Has Rotated One Eighth of a Revolution

sults, as there is no e.m.f. induced in these loops in this position. Loops B and D are connected in parallel between the brushes, and the e.m.f. between the brushes is that induced in either loop B or D, which is supposedly the same. Now, as the armature rotates from the position shown in Fig. 19, the e.m.f. in loops B and D decreases in value and the e.m.f. in the loops A and C increases in value, starting with zero. A small angular rotation of the armature results in the short-circuit of the loops A and C being removed, and the loop A is connected in series with the loop B and likewise the loop D is connected in series with the loop C, Fig. 20. This connection remains while the armature rotates for one-fourth revolution from that in Fig. 19, when the loops B and D are short-circuited by the brushes and the loops A and C are in parallel between the brushes. During this one-fourth revolution the e.m.f. induced in loops B and D decreased in value from a maximum to zero value, as shown by the curve *bd* in Fig. 21, and the e.m.f. induced in the two loops A and C has increased in

value from zero to a maximum value, as shown by the curve *ac* in Fig. 21. The e.m.f. between the brushes is the sum of the e.m.f.'s and it is represented by the heavy curve in Fig. 21. The maximum value of this e.m.f. occurs when the loops are making an angle of 45 degrees with the position shown in Fig. 19, or they have turned one-eighth turn from the starting point, to the position in Fig. 20. The e.m.f. in all the loops is the same for this position of the armature and is equal to 0.707 of the maximum e.m.f. The total e.m.f. between the brushes is equal to twice this value, since two loops are in series, or it is equal to 1.414 times the maximum e.m.f. that can occur in any one of the loops. The e.m.f. between the brushes will

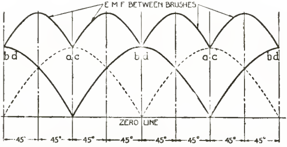


Fig. 21. Curve Representing Variation in Value of Electromotive Force between Brushes of Direct-Current Generator Shown in Fig. 19

fluctuate between the maximum value occurring in a single loop and 1.414 times this maximum value. With a four-loop armature there will be four of these pulsations for each revolution, as shown in Fig. 21. As the number of loops and segments is increased the amount of this fluctuation is decreased (the height of the rise and fall of voltage wave, Fig. 21) but the number of fluctuations per revolution is increased.

In Fig. 22, the number of loops of wire and commutator bars has been increased from 4 to 8. Conductors *A, B, C*, etc., connect on the rear to similarly lettered conductors *a, b, c*, etc. In order to simplify the drawing these connections are not shown in Fig. 22. Note that the direction of the flow of current in the conductors is indicated by the dot or the plus sign inside the conductor; also the position of the brushes has been shifted to the horizontal center line of the poles. This enables the leads from the coil to the commutator bars to be

shorter and more uniform in appearance. The position of the brushes can be changed by moving the leads from the coil to a different commutator bar. In most of the modern direct-current armatures, the coil leads are made about equal in length and the brushes are located in position shown in Fig. 22 in relation to the poles.

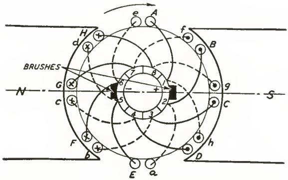


Fig. 22. Diagram of an Armature Having Eight Loops of Wire and Eight Commutator Segments

Open- and Closed-Circuit Armature Windings. In an open-circuit winding the different loops do not as a whole form a closed circuit, but each loop is in circuit only when the commutator segments to which it is connected are in electrical contact with the brushes. The windings shown in Figs. 14 and 16 are of the open-circuit type.

A closed-circuit winding is one in which the loops forming the winding are interconnected and form one or more closed circuits upon themselves, and each loop is always in circuit except when it is short-circuited by the brushes. The winding shown in Figs. 19, 20 and 22 is of the closed-circuit type.

Practically all modern armatures are of the closed-circuit type.

REVIEW QUESTIONS

1. What does the general term *dynamo* mean?

2. Describe the essential components of a dynamo.

3. Upon what factors does the e.m.f. induced in a conductor moving in a magnetic field depend?

4. Why is it that a conductor, moving at an angle of less than 90° to lines of magnetic force, generates a lower voltage than a conductor moving at the same speed but cutting the lines of force at an angle of 90°?

5. What is necessary to maintain a constant potential in a conductor moving in a magnetic field?

6. How do you explain that an armature revolving in a uniform magnetic field generates a *sinusoidal waveform* such as the one illustrated in Fig. 10 on page 272?

7. What does the abbreviation $E_{max.}$ refer to? The Greek letter θ?

8. What effect does adding more series turns to an armature have upon the e.m.f. generated?

9. How many degrees of rotation of an armature constitute a cycle?

10. In what way is the generated e.m.f. taken from a revolving armature without twisting the leads?

11. Sketch the waveform generated by a one-loop armature with a two-part commutator. By a two-loop armature with a four-part commutator. By a three-loop armature with a six-part commutator. How many peaks of voltage are there per cycle for each of the three types of armatures?

12. What is the effect of paralleling armature loops?

APPLICATIONS TO INDUSTRY

1. In telephone work, it is necessary to produce a steady direct-current voltage. Which would give better results: an armature with a small number of turns or one with a large number of turns and commutator segments?

2. What type of current is furnished your home? Of what frequency and amplitude is it?

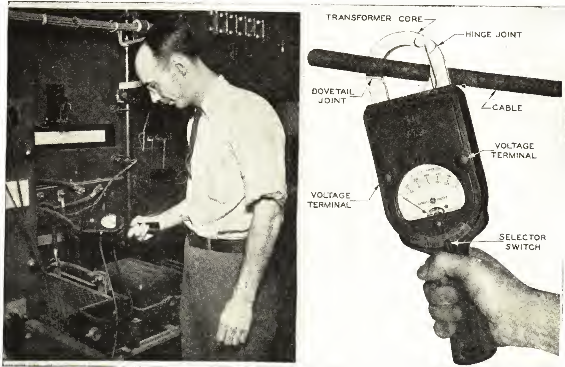
3. In generator No. 1 the conductors on the armature cut 2,160,000 lines of force per revolution and make 1,800 revolutions per minute; in generator No. 2 the conductors on the armature cut 3,320,000 lines of force per revolution and run at a speed of 900 revolutions per minute. If the numbers of conductors on both armatures are the same, which one will generate the higher voltage?

4. Of what type are most modern armatures?

5. What is the essential difference between an alternating-current generator and a direct-current generator?

6. What type of generator is necessary to charge a storage battery?

7. How many lines of force would have to be cut per second to generate a potential of 110 volts?



HOOK-ON TYPE VOLTMETER-AMMETER FOR TAKING CURRENT OR VOLTAGE READINGS

The transformer core opens at dovetail joint for quick insertion over cable. Pushing selector switch to left gives full scale range of 15, 60, 150, or 600 amperes; pushing selector switch to right gives 600 or 150 volts.

Courtesy of General Electric Company, Schenectady, New York

TYPES OF DIRECT-CURRENT MOTORS

Fundamentally there is very little difference between direct-current generators and direct-current motors. Many companies use the same frame sizes and armatures to produce generators and motors; however, there is a slight difference in shunt field windings.

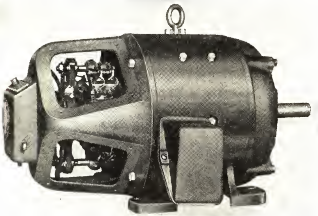


Fig. 1. General-Purpose, Direct-Current Motor
Courtesy of Century Electric Company, St. Louis, Mo.

In order to use a field rheostat for voltage control with self-excited machines, the field coil resistance must be somewhat less for a generator, otherwise, the machines would be identical in construction. As generators usually run in the same direction and motors are often required to reverse rotation, there is sometimes a difference in the set-up of the brush rigging to give different angles to the brushes.

There are many more types of motors than generators as it is much easier to control operating conditions for generators than it is for motors. For this reason motor designers have tried to meet industry's needs, and many more types have been developed. A wider variety of applications also requires a greater number of

characteristics in motors than are necessary with generators. Fig. 1 shows one type of frame which is made up for either generators or motors. Frames used interchangeably are usually of the open type as more often the smaller generators are not enclosed.

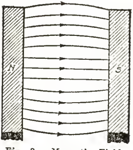


Fig. 2. Magnetic Field Between Poles

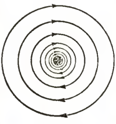


Fig. 3. Magnetic Field About an Armature Coil

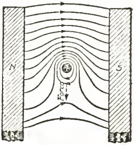
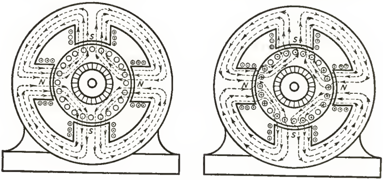


Fig. 4. Magnetic Field Produced by Poles and an Armature Coil



A B

Fig. 5. Magnetic Field of a 4-Pole Motor and Armature

PRINCIPLES OF OPERATION OF MOTORS

Note the flux produced by the poles in Fig. 2 and also the flux produced by the armature coils in Fig. 3. When these two fields are combined (as they are in the air gap of a motor), the result shown in Fig. 4 is produced. The result of the magnetic action of the field flux on armature flux produces a force. Since the armature is built upon a shaft which is free to move, this force called torque tends to turn the armature. Note that the direction of the force is away from the flux concentration. The distortion of the

pole flux caused by the magnetism of the armature produces the torque which turns the motor armature. Fig. 5 shows how this is accomplished in a 4-pole machine. Section *A* shows the pole flux when no current flows in the armature. As soon as current is introduced into the armature conductors, the flux produced causes the pole flux to take the position shown in section *B*. This distortioı effect which results in torque, and rotates the armature, is called armature reaction.

The Left-Hand Rule is a ready reference to help remember the three factors involved, namely current direction, flux direction, and resulting motion. Referring to Fig. 6, the index finger indicates the

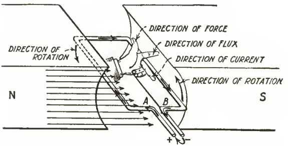


Fig. 6. Application of Left-Hand Rule to an Armature Coil

direction of the magnetic lines, the second finger the direction of current, and the thumb the resulting motion or direction of force. Should these directions become confused, just remember the motion is away from the flux concentration, and the armature will rotate in that direction.

DESCRIPTION OF TYPES

Direct-current motors are classified electrically from their field windings. As the field coils are wound with series, shunt, and combined series and shunt windings, the types are called series, shunt, and compound. In addition to the above may be added the interpole and the compensated winding motor, but any one of the first three types may have interpoles and also compensating windings. Direct-current motors have a decided advantage over alternating-current motors, particularly in speed adjustment and regulation. As this is a very important consideration in factory production.

some types of factories are equipped almost entirely with direct-current machines

Series Motor. The series motor field is obtained from a low resistance coil connected in series with the armature. This condition necessitates all the line current passing through the field of this motor—hence the name series motor. Series motors are especially adaptable to transportation and crane work. The tremendous

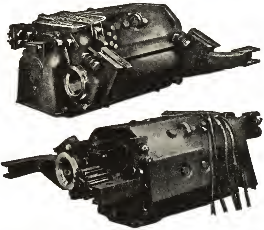


Fig. 7. Upper Illustration Shows the Axle Side of a 600-Volt Railway Motor and the Lower Illustration Shows the Suspension Side
Courtesy of General Electric Company

starting torque characteristic and efficiency at high speeds make them very acceptable for street railway and vehicle use. Due to danger of racing on light loads, series motors must never be used unless they can be geared to the load or otherwise protected against racing. Fig. 7 shows a street railway motor developed for use on light weight cars. Note the totally enclosed features making it dust and water tight.

Another important field of application for the series motor is found in the small appliances using universal motors. Fig. 8 shows an exploded view of one of these machines. The bearings and stator must be held in the appliance which the motor powers.

The series motor gives the best torque at very slow speeds. Its starting and accelerating torque is the best of any motor. The

highest speed is attained at light loads when the armature current is at a minimum. The efficiency is consistently high over a wide range.

The mill type motor is a rugged heavy-duty series motor developed especially for shovels, dredges, cranes, hoists, bridges, and steel mill auxiliaries. The frames of these motors may be obtained

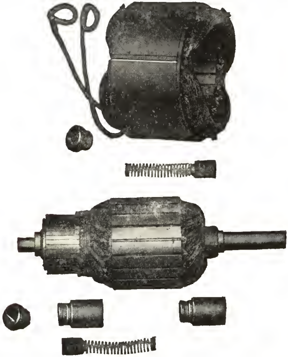


Fig. 8. Parts of a Small Series-Wound Fractional Horsepower Motor
Courtesy of General Electric Company

enclosed, semi-enclosed, drip proof, self- or separately-ventilated to meet the conditions of the installation. This type of motor may also be obtained in either shunt- or compound-wound for constant or adjustable speed. The armature shaft is extended on both ends and finished with a taper. The attachments are keyed and locked with a nut and washer to insure a permanent safe tie to the load. Fig. 9 illustrates the mill type motor just described, and Fig. 10

shows the upper half of this motor opened up for inspection and repairs.

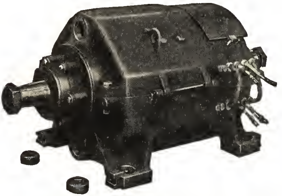


Fig. 9. A Direct-Current Compound-Wound Mill Type Motor
Courtesy of General Electric Company

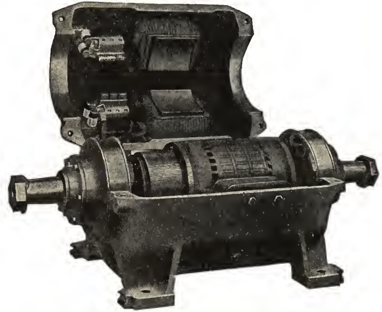


Fig. 10. A Mill Type Motor Opened Up for Inspection or Repairs
Courtesy of General Electric Company

Shunt Motor. The shunt motor has a high resistance field coil which is connected directly across the line in parallel or shunt with

the armature. This circuit condition gives the name shunt to this type of motor. The shunt motor is one of the most common types of direct-current motors. It is best adapted for use where the starting torque requirements are no larger than the running torque. It gives more nearly a constant speed than any other direct-current motor and efficiencies are best from 75 per cent to 125 per cent load. Motors of this type are especially applicable to lathes, line shafting, and woodworking machinery. Fig. 11 shows a partial assembly of a ball-bearing, fully-enclosed, fan-cooled shunt motor. The torque of the shunt motor is directly proportional to the line current, and the speed drops only slightly as the load is added. If the motor is over-loaded until it starts to heat, the speed drops more rapidly as load is increased.

The shunt motor reaches its highest speed at no load. As the motor voltage, which is the voltage generated by the armature rotating in the pole field, very nearly equals the line voltage, the speed cannot be increased unless the field current is reduced. This motor voltage called counter electromotive force opposes the line voltage and limits the line current flowing to the armature. As load is added to the motor, the speed is slightly reduced, which in turn lowers this counter electromotive force, permitting more current to pass through the armature. This additional current strengthens the magnetic field of the armature and gives added torque to meet increased load conditions.

When the load is removed, the unused torque speeds up the armature, increases the counter electromotive force, and this in turn reduces the line current to the armature. The counter electromotive force acts as a very effective governor in the shunt motor which makes electric motors highly efficient as power machines.

Compound Motor. The compound-wound motor has both a shunt and a series coil on each of the poles. This construction gives a motor the combined characteristics of the shunt and series machines. Its speed is not excessive at light loads; it has considerable starting torque; and a larger variation of speed with load than the shunt motor.

The compound motor is used where a large amount of friction and inertia is met when starting a load. It will give a more rapid acceleration than the shunt motor and is safe from excessive speed

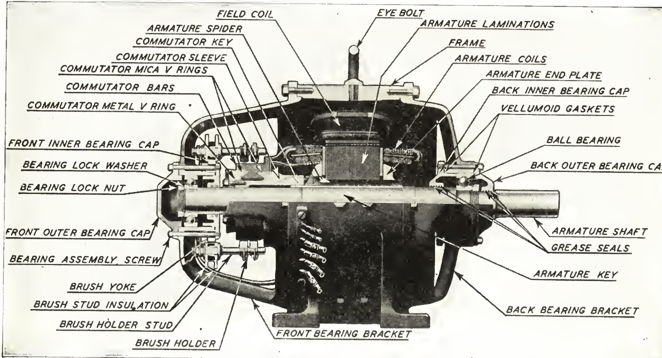


Fig. 11. A BALL-BEARING FULLY-ENCLOSED FAN-COOLED DIRECT-CURRENT MOTOR
Courtesy of Reliance Electric and Engineering Company

with no load. Motors of this type are used in elevators, punch presses, roller mills, conveyors, and pumps.

Practically any frame used for a shunt motor can be used as a compound. In fact, most direct-current motors can be obtained with either shunt or compound windings. Fig. 12 shows a direct-current motor frame for elevator service. This machine is built with shunt or compound windings in all voltages and sizes.

Interpole Motor. The interpole motor has a small pole between each pair of main poles. The purpose of these poles is to aid

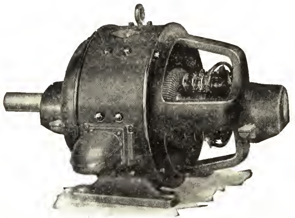


Fig. 12. Open Type Frame of a Direct-Current Elevator Motor
Courtesy of Imperial Electric Company

commutation by neutralizing the cross-magnetization of the armature. When this is accomplished, the pole flux is not distorted and the commutating position of the coil under the brush is not changed. This permits proper commutation of the coil.

Interpole motors are used where considerable fluctuation of load occurs and also where reversing duty is a requirement. A shunt, series, or compound motor may be equipped with interpoles. Interpoles, often called commutating poles, insure sparkless commutation on motors from no load to 125 per cent load without shifting the brushes. Fig. 13 shows a compound-wound motor frame with commutating pole windings. This motor is built in sizes from 25 up to 700 horsepower but interpole motors are available in all sizes, both larger and smaller.

REVIEW QUESTIONS

1. In what ways does a *direct-current generator* differ from a *direct-current motor?*

2. What is *armature reaction?*

3. In the left-hand rule, what do the thumb, index finger, and second finger indicate?

4. Describe the arrangement of the field coils in the series, shunt, and compound direct-current motors.

5. What are the outstanding characteristics of the three basic types of direct-current motors?

6. For what class of service is each best fitted?

7. Under what conditions are *direct-current* motors superior to *alternating-current* motors?

8. Describe an interpole motor and the type of service to which it is put.

9. What is a *compound motor* and where is it usually used?

10. What does the term *torque* mean with reference to motors?

APPLICATIONS TO INDUSTRY

1. What type of motor is usually used for electric cranes, streetcars, and electric railways? Why?

2. At what point is the counter e.m.f. of a shunt motor the greatest?

3. What percentage of load will an *interpole motor* carry without shifting the brushes?

4. Why is it necessary to insure that a series motor will always be under load?

5. Why are heavy industries almost generally equipped with direct-current motors?

6. Why is the shunt motor especially applicable to lathes, line shafting, and woodworking machinery?

7. If you had a punch press for which you needed a motor, what type of direct-current motor would you select?

RECTIFIERS

Rectification of Current. To *rectify* means to correct or make right. *Rectification of current,* then, means the changing of the type of current which is the source of your supply into that particular type which you may wish to use. For example changing alternating current into continuous-direct current.

This may be accomplished with different devices, such as, converters, inverted converters, motor-generator sets, separate generators driven by motors, or with any one of the several types of plate, bulbs, or tube rectifiers.

The choice of any one of the devices, named in the foregoing list, depends almost entirely upon the type of current of your source of supply and upon the type of current you may wish to obtain. Consideration also must be given to the amount of space available for your equipment and the amount of time available for its care and operation. For certain purposes some of these devices are better than others. Though the desired results can be obtained, in most cases, with the more expensive devices of the group—the motor-generator set or the separate motor and generator in combination—other less expensive devices may serve your purpose satisfactorily and also require less care and attention.

Types. The ordinary lighting circuit of the home is the source of current supply most commonly used. Almost universally—although there are some exceptions—this is alternating current ranging from 110 to 120 volts. Let us say, for example, that you desire to charge an automobile storage battery from this circuit. The battery requires about 7 to 8 volts of direct current. Perhaps the best choice of equipment for this job as far as performance is concerned is the *motor-generator set.* In this particular equipment you would choose a set which had incorporated into its case, or frame, an alternating-current motor of a rating suitable to that of your current supply. This would furnish the power to drive the rather low-voltage direct-current generator which is also a part of this set. This generator would be equipped with the proper field controls

to regulate the current and you would obtain from this set the maximum in exactness of battery charge. Or, you could choose for this job a more simple device in which a *vacuum tube* of a suitable type is employed to intercept and hold back one-half of the alternations from your supply line, allowing the other half of the *sine wave,* which is flowing in the proper direction and at a reduced voltage to charge your battery. While either of the foregoing methods will rectify current in a way, the latter device is the one known to the trade as a *rectifier.* Both methods have advantages and disadvantages in cost, in maintenance, and in results obtained. The choice between them depends upon which method is more advantageous for your particular job.

Some of the machines, or devices, which are listed are better adapted to some jobs than they are to others. However, the entire range of service can be covered usually with one or the other of the devices as you will see after reading the following explanations.

Converters. The *converter* is a machine employing mechanical rotation for changing electrical energy from one form of current to another form, *i.e.,* it functions as a double-current generator. In appearance it is somewhat similar to a motor or a generator. It is equipped with an *armature* which carries both a *commutator* and a set of *collecting rings.* These are usually installed upon opposite ends of the armature shaft and are separated by the *laminations* and *windings* of the armature.

Its function is to change alternating current to direct current or, conversely, to change direct current to alternating current. When direct current is changed to alternating current the machine is usually referred to as an *inverted converter* or simply called an *inverter.*

Inverted Converters. The inverted converter is perhaps the most simple of construction, for it does not need to be as complicated in design as some of the other forms of this machine. This is true because it is operated as a *direct-current motor* and the *direct-current armature* with which it is equipped lends itself readily to the addition of collecting rings for taking off the alternating current. This armature is shown in the sketch of Fig. 1. The armature bears the usual windings placed in slots in the *core.* There are wires connecting each of the collecting rings to the commutator at

certain definite points. These connections are made to bars of the commutator which rest, at any one given instant, exactly under adjacent *brushes*. In the armature of a four-pole machine such as we have shown in the illustration the connections, then, are ninety degrees apart. In a two-pole machine the connections would be 180 degrees apart. It is the simple addition of the collecting rings and their connections to this direct-current armature that makes this machine a converter. In all other respects it is a direct-current motor. In fact, it still operates as a direct-current motor, but it drives no

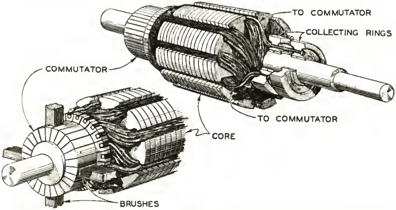


Fig. 1. Converter Armature Showing Method of Connecting Collector Rings to Commutator

mechanical load. Instead, its job is to deliver alternating current from its collecting rings.

In order to understand the functions of a converter which changes alternating to direct current, you should recall that all generators actually generate alternating current. It is only by means of a commutator that alternating current is changed to direct current even in what is known as a *direct-current generator*. In any direct-current generator the commutator is fixed rigidly upon the same shaft with the laminations and windings of the armature. It is fixed in an exact position so that the changes in the alternations produced by the armature will arrive at and be switched to the proper brush at the proper fraction of an instant. Perfect timing is necessary and this timing is correct and in step, or synchrony, with the alternations as they are produced. When this is so, the maximum in direct-current output is obtained. If the commutator is

shifted even in the slightest degree the output of direct-current is decreased and sparking occurs at the points of brush contacts.

Synchronous Converters. While a commutator is usually mounted upon the same shaft with the armature, it does not have to be. It may be in another room or even in another part of town. The only requirement is that the commutator be driven in step, *i.e.*, in synchrony, with the alternating current it is to convert. This, then,

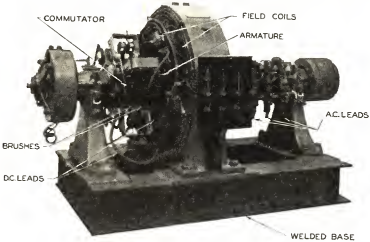


Fig. 2. Polyphase Synchronous Converter
Courtesy of General Electric Company, Schenectady, N. Y.

is the function of a converter. Converters for this job are built as *synchronous motors* which are designed to run in step with the current from the alternating-current generator which drives them. They are called *synchronous converters* and their commutators are as efficient in current conversion as if they were installed upon the alternating-current generator which is supplying the current, even though that generator may be many miles away.

Synchronous converters are among our most complicated and involved machines. They have to be built with perfect accuracy and usually require constant supervision during operation.

Converters may be wound for either single or polyphase operation. However, when single-phase converters are operated from the alternating-current side, that is, when alternating current is to be changed to direct current, they are not self starting. They

must be started and brought up to speed with an outside source of power, but this source may be cut off once the machine is up to speed; it will continue to operate under its own power unless something occurs to cause it to fall out of step with the operating current. In such a case, it will stop and must be started again by the outside power source.

However, polyphase converters are self starting and most of the larger converters are of the polyphase type. An illustration of a polyphase type is shown in Fig. 2.

The current output of a converter is not as easily adjusted

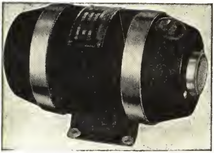
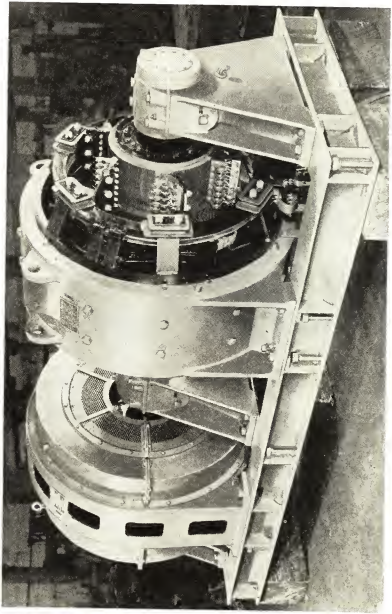


Fig. 3. Small Rotary Converter
Courtesy of Carter Motor Company, Chicago, Ill.

over as wide a range of values as that of a motor-generator set. Therefore most converters are built to supply stated voltages.

Among the smaller converters we find one weighing about twelve pounds for use with testing equipment and radio amplifiers. This is shown in Fig. 3 and is used to convert direct current to alternating current.

Motor-Generator Sets. Motors and generators can be put together in sets in almost any combination. They may have high-voltage motors driving low-voltage generators, or the opposite may be true. Alternating-current motors are put into sets with direct-current generators, and we find direct-current motors driving alternating-current generators. The motor must be of a rating which will operate upon the source of current supply, whether it is alternating or direct current, but the generator may produce current of any kind or of any voltage that you choose. If the generator is to supply direct current, the set may have mounted upon it or near



LARGE MOTOR-GENERATOR SET

At the left is a 2,300-volt, 3-phase, alternating-current motor that is directly coupled to a 500-kilowatt, direct-current generator.
Courtesy of Allis-Chalmers Mfg. Co., Milwaukee, Wis.

it, a small switchboard equipped with appropriate switches, a voltmeter, an ammeter, and a rheostat for the control of the generator field, as shown in Fig. 4. This is such a set as described, in the early paragraphs, for battery charging.

Ordinarily, in sets of smaller ratings, the motor and the generating units are mounted close together on the shaft with only two bearings employed.

Dynamotors. A rotating device known as a *dynamotor* acts as both a motor and generator. It is used to change a direct-current voltage to an alternating-current voltage or to some other direct-

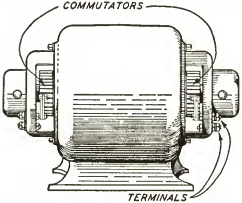


Fig. 5. Dynamotor Used to Change Voltage of Direct Current

current voltage. Dynamotors are types of motor-generators. They are greatly condensed and sometimes are built with a single field and a double-wound armature with two commutators as in Fig. 5; sometimes they are built with two separate armatures.

Dynamotors are usually built in small sizes. An excellent example of this machine is the Carter Magmotor shown in Fig. 6. It is roughly $5 \times 3 \times 2$ inches in size, weighs less than five pounds, and has an output of 100 watts. Permanent magnets are used in the fields. This machine is designed for police-car radios, small aircraft transmitters, and similar uses.

Motor-generator sets need not always be thought of as small affairs. Many industrial plants employ this method of current conversion and, sometimes, these sets are huge machines.

Many of these sets are composed of two separate machines

mounted upon one base and connected together with couplings on the projecting shaft ends.

Individual motors driving individual generators make up another type of this equipment. These motors may be geared or belted to each other to obtain the driving action. However, if the two are connected together in a direct drive by means of some type of coupling a motor-generator set is formed.

Rectification of Alternating Current. In previous paragraphs our discussion centers around the conversion and generation of current by means of the generator operated by a motor. We saw that in

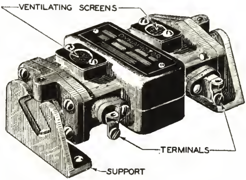


Fig. 6. Small Dynamotor Sometimes Called Magmotor
Courtesy of Carter Motor Company, Chicago, Ill.

the case of the motor-generator set, an entirely new current was generated. We did nothing at all with the current we used from our power source but run a motor. We used no part of the original current at all in the new circuit.

In the case of the converter, we found the action to be centered around the action of the commutator. We may feed direct current into the converter and run it as a direct-current motor. However, when this current is once inside the armature, it is changed to the exact form the current would have if the converter were run as a direct-current generator by means of some outside power source. In other words, if we remove the current from the armature through the slip rings, before it passes through the commutator, we obtain alternating current, and if we remove it after it passes through the commutator we obtain direct current. The commutator is then our

rapidly moving switch standing on guard and seeing that current passes in one direction only over our outside direct-current wires. The commutator is then, perhaps, our best method of rectification. It takes sine-curve loops such as those which lie below the zero line on our sine-curve graph, Fig. 7, and places them above that line, smoothing them out for the direct-current action.

Let us now study the graph of the *sine curve* as shown in Fig. 7. Alternating current is in reality just two direct currents; one making a flow of the complete circuit in one direction and the other flowing through the complete circuit in the opposite direction. The flow of current in one direction is depicted by the loops above the zero line of the graph and the flow of current in the opposite direction is shown by the loops below the zero line.

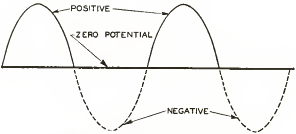


Fig. 7. Sine-Wave Alternating Current

If we could block out either set of these loops entirely, we would have left an intermittent, or pulsating, current flowing only in one direction. The commutator of our converter would change the negative impulses to positive, and the current would become pulsating. That is, both sets of loops would appear on the upper side of the zero line. In doing this we are taking advantage of both halves of the sine wave. We would still have a direct current were we to use but one-half of the full wave, although then we would be discarding one-half of our current effect. A method of rectification which utilizes both halves of a sine wave is called a *full-wave rectifier,* one which utilizes but one-half of the full wave is called a *half-wave rectifier.*

If we could introduce into an alternating-current circuit a device similar in action to the *check valve* which is sometimes employed in water piping to keep the flow of water from reversing

itself and, by so doing, block out the set of loops of the curve which we had decided not to use (the negative impulses, shown dotted, Fig. 7), we could effect a rectification of current. This current remaining would be of the half-wave form and would be intermittent in its flow. There are some current applications where a half-wave will suffice. It will serve for battery charging, and there are devices in commercial use which do just this thing. Let us take up some of the methods.

Copper-Oxide Rectifiers. It has been discovered through laboratory experiments that when a copper plate or washer has one of its surfaces exposed to an intense heat, a copper oxide will form upon

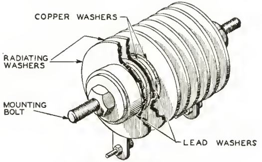


Fig. 8. Copper-Oxide Rectifier

that surface. It has been found, also, by tests that when a current is passed through the copper washer and its oxide coating, the current meets extremely high resistance when flowing in one direction, but meets scarcely any resistance when flowing in the opposite direction. Further tests have revealed the fact that when an alternating current of proper voltage is introduced across the washer, current will flow freely during one-half of the cycle but scarcely any current will flow during the other half of the cycle. Thus the experimenter discovered his *check valve.* He discovered a method for blocking off half of the loops of the curve and retaining the other half. He found the device for *half-wave rectification.* He not only discovered the way to accomplish this rectification, but he had found a form of rectification which uses no mechanical motion, and has no wearing parts. However, he saw that it is necessary to use several of these discs (Fig. 8) to withstand electrical pressures and that it is

advisable to hold temperatures down, by some form of cooling. When the temperature of the oxide-coated copper washer rises above a certain point more current will flow at the time current should flow and also more current will flow at the time current should be blocked off. So temperatures must be brought down to a point where as little as possible of the negative current will leak through.

In this washer of copper with its coating of copper oxide on one of its surfaces, current that is flowing from the copper-oxide side toward the copper washer will pass through readily but current flowing from the copper to the oxide is almost completely blocked off. It is the actual junction between the copper of the washer and the oxide formed upon it which possesses this remarkable characteristic of either passing or holding back the current.

These prepared washers are assembled upon a *mounting bolt* with *lead washers* held firmly against the oxide side for better electrical contact. Usually sufficient cooling of the unit can be accomplished by the introduction of *radiating washers* of a somewhat larger diameter between the *copper washers*. Sometimes fan cooling is added. The copper-oxide rectifying unit is shown in Fig. **8**.

These rectifying units have many uses. They make excellent battery chargers and they have their uses in radio and telephone work. They are used to actuate magnets and relays. The heavier units are employed in many applications in industry.

Usually a *transformer* is found necessary to reduce the voltage of the circuit before current is sent through the unit itself. There are a few applications where this is not found necessary. If one unit is used alone a *half-wave* is rectified. This circuit with *transformer* is shown in Fig. 9. When two *rectifier units* are used in a circuit, as shown in Fig. 10, a *full wave* is the result. A much better arrangement for full-wave rectification is the four-unit rectifier connected in *bridge formation* as shown in Fig. 11. The bridge method results in a much smoother current in the rectified circuit.

Selenium Rectifiers. The *selenium rectifier* does the rectification job in much the same general manner as does the copper-oxide rectifier. The elements by which the rectification is produced are of a different material and the characteristics are slightly different.

In the selenium rectifier the iron washers are coated with

selenium. *Selenium* is a nonmetallic element which chemically resembles sulphur, and is sometimes used in photoelectric cell construction. On top of this coating of selenium is placed a coating of a special alloy for the purpose of making a good electrical contact to the other parts of the circuit. These *selenium-coated washers* are

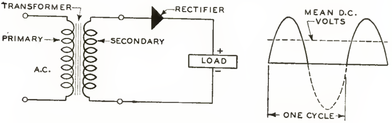


Fig. 9. Single-Phase Half-Wave Rectifier Circuit and Voltage Wave

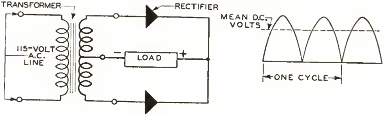


Fig. 10. Single-Phase Full-Wave Center-Tapped Rectifier Circuit

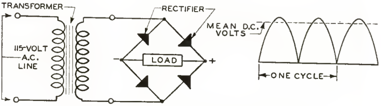


Fig. 11. Single-Phase Full-Wave Bridge-Type Rectifier Circuit

assembled in stacks in much the same manner as the copper-oxide washers, and the hookups in which they are used in circuits are the same. These circuits are shown in Figs. 9, 10, and 11.

The selenium-coated washer (Fig. 12) has, at the point of contact of the selenium with the iron of the washer, the valuable property of either conveying or blocking off current depending upon the direction in which current is passing through the washer. The

rectification is again at the junction of the selenium and the coating material, and the action is much the same as we found in the case of the copper washer with the copper-oxide coating. Since the action is wholly in the selenium-coated washer itself and does not require a washer of lead to complete the contact to the washer surface it is not so necessary to employ such heavy pressures in the stack assemblies. Therefore expansion and contraction of the *assembly and mounting stud* do not change the electrical contact. Higher plate temperatures are permissible with the selenium rectifier with less need for fan cooling. A selenium unit is shown in Fig. 12. The

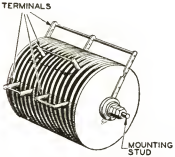


Fig. 12. Selenium Rectifier Unit of the Bridge Type

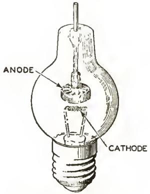


Fig. 13. Tungar or Rectigon Rectifier Bulb

terminals are connected to the *transformer* and *load* as shown in Fig. 11.

The selenium rectifier operates at a temperature approximating the temperature of associated equipment. This higher temperature permits better cooling and therefore operation at higher current densities than copper oxide without the use of fan cooling. Individual disks operate at about three times the back voltage of a copper-oxide disk. Both of these conditions result in a smaller, lighter rectifier of good efficiency.

Charging Batteries by Means of Rectifying Bulbs. A rectifying bulb, resembling the ordinary light bulb, contains a low-voltage filament called the *cathode,* Fig. 13, and also a plate electrode called the *anode;* the bulb is completely filled with an inert gas, *Argon,* which is the rectifying medium. When the filament in this bulb

is heated, electrons are emitted to the plate electrode. The electrons pass from the *filament,* or *cathode,* to the *electrode,* or *anode.* Since current is said to travel against the passage of electrons, the current will flow from the anode to the cathode and no current will pass from the cathode to the anode; hence, this bulb will act perfectly as a rectifying agent. It is manufactured in several sizes, these dif-

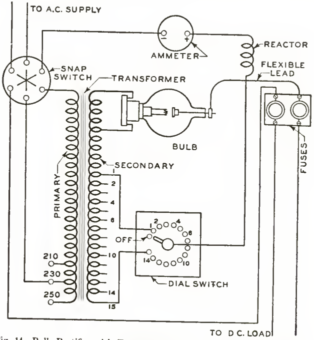


Fig. 14. Bulb Rectifier with Transformer for Use on 230-Volt Alternating-Current Circuit

ferent sizes being determined by the number of amperes the bulb will pass while rectifying.

We have already stated that the filament of this tube was of a low-voltage rating, so this means that a *transformer* must be included in its circuit for the purpose of voltage reduction. There are two types of transformers permissible. The usual transformer type is a *transformer* with two *windings,* Fig 14, one for the *line circuit* and one for the *charging circuit.* The line-circuit winding on this transformer is called the *primary* and is of higher voltage than the charging-circuit winding, which is called the *secondary.* There

must be a special type of winding on the secondary of this transformer. It must have a few turns of heavy wire to supply the current to power the filament of the bulb; then added to this, in electrical connection, must be a winding of many more turns of somewhat smaller wire for supplying current to the load on the rectifier. This circuit is shown in Fig. 14.

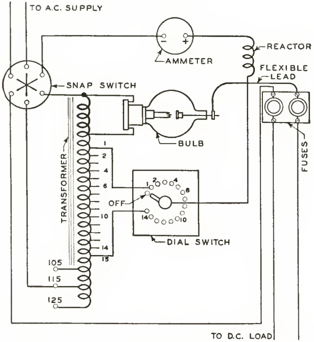


Fig. 15. Bulb Rectifier with Auto-Transformer for Use on a 115-Volt Circuit

Taps are provided on the primary for connections to be used when the voltage of the circuit is low, *210 volts,* or when high, *250 volts.* The taps on the secondary of the transformer (*1, 2,* etc. to *15*) are connected to the contacts on the *dial switch, 1, 2,* etc., counting in a clockwise direction. For clearness and simplicity of the diagram, only two of these taps, *1* and *15,* are shown connected. When the voltage of the circuit is low, the lead is changed from *230* to the *210*-volt tap. If the voltage of the circuit is high, the *230*-volt lead is changed to the *250*-volt tap. This transformer is known as the *mutual-inductance transformer.*

The other transformer which may be used in the rectifier circuit is known as an *auto-transformer*. It is shown in Fig. 15. Although it contains but one winding, this must be of two sizes of wire. For this circuit, there must be the same filament winding in the auto-transformer as shown in the first transformer. Then the remainder of the winding must be similar to that shown in the secondary of the first transformer, but it must have many more turns; enough more, in fact, to hold back the line voltage sufficiently to allow just the same current to flow as was permitted in the secondary of the mutual-inductance transformer.

The auto-transformer is simpler to construct than the mutual-inductance transformer, hence it is cheaper. It will do its work equally as well as the more expensive mutual-inductance transformer, but there is an element of danger connected with its use. In the mutual-inductance transformer there is no part of the line current, or voltage, which gets into the secondary coil or rectifying circuit; therefore, there is no danger of shock to the person when handling the battery clips with the current on. The auto-transformer carries full line voltage on one of the battery clips, and the danger from shock is great.

The Westinghouse Electric & Manufacturing Company manufactures these bulb rectifiers under the name of *rectigon*. General Electric manufactures them under the name of *tungar*. Rectigon and tungar bulbs are interchangeable. Either of these sets makes an excellent battery charger and they are used extensively in battery shops and for general battery charging.

VACUUM TUBES USED IN RADIOS

Diode Tube as a Rectifier. Direct current is required to supply constant potentials to the plate and grid elements of the vacuum tubes used in radio circuits. Therefore, it becomes desirable to convert the alternating current used in lighting circuits into direct current. This is accomplished by means of the diode tube serving as a rectifier. At the same time, it is desirable to have voltages higher than those available on the electric lighting and power lines.

Higher voltages can be obtained by the use of transformers with alternating current. Direct current cannot be stepped up through a transformer. This means that in order to secure the higher

direct-current voltages, it is necessary to provide a higher voltage alternating current and convert it into direct current.

Half-Wave Rectifier Tube. There are two forms of rectification —*half-wave rectification* and *full-wave rectification.* The name given the rectifier depends upon whether the process uses only one side or both sides of the alternating-current wave. Half-wave rectification requires the use of a vacuum tube consisting of a *filament* and a single *plate,* as shown in Fig. 16. While the construction is different, the principle of operation is the same as the tungar rectifier.

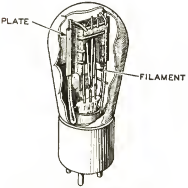


Fig. 16. Half-Wave Rectifier Tube

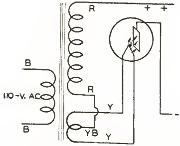


Fig. 17. Diagram of a Half-Wave Rectifier Tube Circuit

Fig. 17 shows a diagram of a *half-wave rectifier tube* in conjunction with a *transformer.* The transformer consists of a primary winding *B-B* and two secondaries, one of which is to step up the voltage, the other to step down the voltage. The voltage delivered by the secondary winding marked *Y, YB, Y* is that required on the *filament* of the rectifier tube according to the specifications of the tube manufacturer. The voltage delivered by the secondary winding marked *RR* will vary according to the requirements of the circuit —the value of the direct-current voltage needed to operate the device with which the rectifier is connected. The letters are the abbreviations of the color of the insulated leads coming out of the case; thus *B* is for *black, R* is for *red, Y* is for *yellow,* and *YB* is for a *yellow* and *blue* striped design.

It will be seen that the terminals of the high-voltage secondary will be alternately positive and negative as the alternating current

reverses its direction of flow, which means that the charge upon the plate—through the external circuit—will be positive and then negative with each alternation of the current.

When current is passed through the filament of the tube, electrons are liberated into the space. When the current is *positive*, in that part of the cycle, there will be a positive charge upon the plate, at which time the plate will attract the *negative* charges given off by the filament, thus causing a flow of current. However, as the current reverses its direction of flow, the plate becomes charged negatively and repels the electrons, and there is no current flow. Thus, a condition such as represented by Fig. 7 is created. Each of the alternations above the *zero potential line* is retained, while the alternations indicated by dash lines below the zero potential line are eliminated. This means that the current flowing through the circuit, though pulsating, is flowing in the same direction and does not reverse its direction of flow. The pulsations are eliminated —or minimized—by the use of filter circuits.

The electron flow from the rectifier circuit is shown by the polarity symbols (Fig. 17). The negative charges, or flow of electrons, pass from the filament to the plate, Fig. 17, and out through the external circuit, returning through the high-voltage winding of the transfer *RR* to the center tap of the filament supply secondary, *YB*, and thence to the filament. All this action takes place only during that part of the cycle when there is a positive charge upon the plate of the rectifier tube.

Full-Wave Rectifier Tube. A vacuum tube that has a *filament* and two separate *plate elements* is required with full-wave rectification. The construction of an early rectifier tube is shown in Fig. 18. The two filaments inside the glass bulb are joined in series with each other. The principle of the *full-wave rectifier* is identical with that of the half-wave rectifier. The difference lies in the fact that both sides of the wave are converted, one of them being transposed to the opposite side of the zero potential line.

A typical circuit for a transformer and tube for full-wave rectification is shown in Fig. 19. The high-voltage and the low-voltage secondaries are both center tapped. As the voltage is induced into the secondary of the transformer, opposite ends of the high-voltage winding are at opposite polarity—when one terminal

is positive the other is negative, and vice versa. Thus, it is evident that each of the plates of the rectifier tube will be charged positively and then negatively as the voltage alternates. It is also true that at the time one of the plates has a positive charge, the other plate will have a negative charge of equal value.

Electrons, that are emitted by the filament, are attracted toward the plate element on which there is a positive charge and are repelled by the plate on which there is a negative charge. As the current reverses, the electrons pass first to one plate and then to the other.

Terminal or lead *R-Y* of the secondary winding *RR*, Fig. 19,

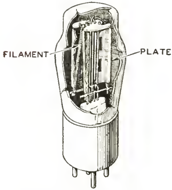


Fig. 18. Full-Wave Rectifier Tube

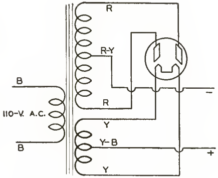


Fig. 19. Full-Wave Rectifier Tube Circuit

is at the electrical center of the high-voltage winding. As the electrons flow from the filament they pass to the plate which is charged positively—say, for example, the right-hand plate—they pass through the upper portion of the high-voltage secondary and out at *R-Y*. The lower half of the winding at this time is negative, which repels the flow of the electrons, and this half of the transformer and the left-hand plate of the tube are inactive during this alternation. As the current reverses its direction of flow, the left-hand plate becomes charged positively and the electrons, again passing from the filament to the plate flow through the lower portion of the high-voltage winding. Returning to the filament circuit, it is only necessary that they find their way back to the filament—through first one and then the other portion of the filament winding. Hence, the polarities are as shown on the diagram, negative off

the center tap of the high-voltage secondary, the positive terminal off the filament circuit.

Mercury Vapor Tubes. The effect of the space charge is present in rectifier tubes as well as in those tubes used for other purposes. The negative charges liberated by the filament tend to repel other electrons so liberated and force them backward away from the plate. Higher plate voltages will counteract the effect to some extent, but not entirely. In order to overcome the effect of space charge, a drop of mercury is placed in some rectifier tubes. The mercury gives off a vapor—minute particles or atoms moving freely inside the tube. When the filament is heated, the electrons moving at enormous velocity strike the mercury atoms and dislodge electrons by collision. The freeing of the negative charges from the mercury atoms causes the vapor to become ionized—carrying a positive charge—thereby neutralizing the space charge and allowing increased flow of current to the external circuit.

RADIO POWER SUPPLY UNITS

In order to furnish the proper voltages for operating the tubes of a radio set, a radio supply unit is used. This unit consists of a *radio power-pack transformer,* a *rectifier tube,* a *filter,* and a *voltage divider.* A wiring diagram of this combination of units is shown in Fig. 20. The transformer connections are similar to those previously studied in connection with half-wave and full-wave rectifier tube circuits. The added unit in Fig. 20 is the filter and voltage divider.

Filters. Voltage pulsations, such as delivered by rectifier tubes, and shown in the wave-form pictures at (*A*) and (*B*) of Fig. 21, cause variations in the output of a circuit. Each of the pulsations causing a varying plate voltage produces a corresponding rise and fall in the flow of plate current. Therefore, it is necessary to introduce apparatus to eliminate the variations and to provide direct current as nearly pure as possible.

Due to the action of a *rectifier tube* of the full-wave type, a 60-cycle alternating current will produce 120 pulsations which must be filtered if the current flow is to be continuous. A half-wave rectifier produces 60 pulsations. In other words, a full-wave rectifier, shown in (*B*) of Fig. 21, produces twice as many pulsations as the original current; a half-wave rectifier produces the same

number of pulsations as the frequency of the current supplied to the device. Higher frequencies are filtered with greater ease than

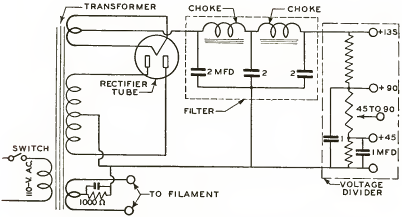


Fig. 20. Wiring Diagram of a Power-Supply Unit of a Radio Set

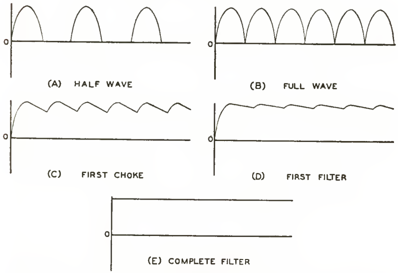


Fig. 21. Wave-Form Picture Showing How Pulsations Are Smoothed Out by Condensers and Choke Coils

the lower frequencies, which means that the 120-cycle impulse is filtered with greater facility than a 60-cycle impulse.

A *filter*, as applied to a radio power-supply device, is a combination of the proper electrical units to effectively produce a pure direct current for distribution to the plate circuits of the various stages of a receiver or amplifier. It consists of condensers and inductance units.

A fluctuating current flowing through an inductance causes a counter-electromotive force that opposes the change of flow of the fluctuating current. A condenser stores an electrical charge and then releases it into the circuit when the pressure is reduced. Both of these phenomena are applied to the operation of a filter in a power-supply device.

Wave Traps. In the design of a filter circuit it is necessary to design what is known as a *wave trap* to eliminate the ripple in the current delivered by a rectifier tube. This wave trap is a filter that will prevent the flow of alternating current and at the same time permit the free flow of direct current. The alternating current is prevented from flowing in that portion of the circuit in which the *choke coil*—an inductance—is connected, and direct current is prevented from flowing in the circuit in which a *condenser* has been connected. On the other hand, however, the alternating current flows through the circuit in which the condenser is placed, and the flow of direct current is retarded in the circuit containing the inductance only by the ohmic resistance of the inductance itself, which, in most instances, is negligible.

Referring now to Fig. 20, the alternating-current—or pulsations delivered by the *rectifier tube*—are effectively stopped by the inductance units (*chokes*) in the positive side of the circuit. However, the condensers connected between the positive and the negative sides of the circuit provide a path for the alternating-current impulses by alternately charging and discharging the plates of the condensers.

Fig. 7 shows the relative wave form of the voltage in the primary and secondary windings of the transformer in a power-supply device. That in the primary winding of the power transformer, Fig. 20, is usually 115-volt alternating current. One of the secondary windings steps down the voltage for the filament of the rectifier tube. Another secondary winding steps up the voltage in order to provide voltages needed for the circuits of the radio

receiver or amplifier. The two secondary windings deliver an alternating voltage that has a wave form identical with that which is passing through the primary windings, Fig. 7.

However, after passing through the rectifier tube, the wave form changes perceptibly, as shown at (*A*) in Fig. 21. Each of the alternations above the zero potential line, Fig. 7, has been retained, and the space between them has been filled with the reverse alternations, as in (*B*) of Fig. 21. The current is now pulsating, but does not reverse its direction of flow.

The first condenser in the filter network assumes a charge during the time when the voltage is increasing in each of the alternations, and gives up its charge during the period when the voltage is decreasing, so that it has a wave form similar to that shown at (*C*) of Fig. 21, before it reaches the left-hand terminal of the *first choke coil*. Fig. 20.

The counter-electromotive force set up in the choke coil retards the change of flow of the pulsating current, and the peak voltages tend to increase the charge upon the plates of the first condenser, thus giving it a still greater charge to fill in the valleys between the peaks of the wave. So, at the output of the first choke coil, the voltage has assumed the form as shown at *D*, Fig. 21.

After the current has passed through the second portion of the filter network, during which time it is subjected to the same process as during the first half of the filter, it assumes a practically steady voltage at (*E*) of Fig. 21, such variations as remain being negligible in their effect upon the radio or amplifier circuits.

The circuit shown in Fig. 20 represents the fundamental type of power-supply unit. In practice, it may be found unnecessary to use more than one choke because a single choke may serve to effectively produce a continuous flow of direct current. The field coil of a loud-speaker may be used as one of the choke coils; or, because of its high inductance, the field coil may serve as the only choke coil required.

Voltage Divider. In order to supply the proper potentials to the various elements of the vacuum tubes in the radio or amplifier stages, it is necessary to make provision for voltages of different values. Fig. 20 shows the *voltage divider* used in earlier models of power units in radio receiving sets, the resistance unit being con-

nected directly between the positive and negative sides of the line so that there is a constant load on the circuit.

Calculation of the values of the resistance units to provide a given voltage, involves an application of Ohm's law, $E = IR$. Thus, by knowing the value of the drop in voltage and the current that will be drawn at that particular potential, the resistance may be calculated readily.

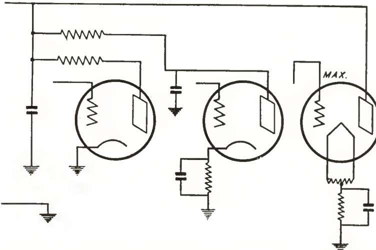


Fig. 22. Method of Using Individual Resistance Units to Obtain Different Voltages for Plate Circuits of a Radio Set

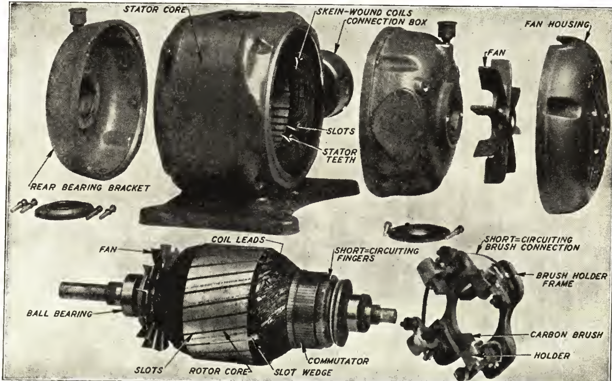
Another method to provide for the distribution of the voltages is to use a resistance unit for each voltage value. Here again, the amount of resistance is determined by applying Ohm's law, taking into account the current drain and the drop in the voltage from the *maximum potential*. An example of a circuit using individual potential-drop resistance units is shown in Fig. 22.

REVIEW QUESTIONS

1. What is *rectification?*
2. What is a *converter?* Explain its function.
3. Describe the function and operation of an *inverted converter.*
4. Explain briefly the fundamental principle of a *synchronous converter.*
5. What are the main components of motor-generator sets and how are they usually assembled?
6. What is a *half-wave* rectifier? A *full-wave* rectifier?
7. Basically, what is the theory of operation of a *copper-oxide* rectifier?
8. In what ways are *selenium* rectifiers superior to copper-oxide rectifiers?
9. Draw a typical output waveform from a *half-wave* rectifier. A *full-wave* rectifier.
10. Explain how a *diode* rectifier rectifies an alternating current.
11. What is the purpose of a *filter* on a radio power supply? Describe the action of the *condenser* and *choke coil* in a filter.
12. Where is the *voltage divider* connected in a radio power supply?

APPLICATIONS TO INDUSTRY

1. Why are large cooling washers necessary in copper-oxide rectifiers?
2. In what way do an *auto* transformer and a *mutual-inductance* transformer differ?
3. Describe two satisfactory methods of charging storage batteries from an alternating-current source.
4. Why is a *transformer* used in a radio power supply?
5. What is a *Tungar* rectifier? A *Rectigon* rectifier?
6. Why is it more advantageous to use a *full-wave* rectifier rather than a *half-wave* rectifier in a radio power supply?
7. What advantage does the *polyphase* converter have over the *single phase* converter?
8. What is the purpose of the transformer used with the Tungar rectifier?
9. Why is a small amount of mercury used in some rectifier tubes?
10. What kind of current is generated in the armature windings of a direct-current generator?



UNASSEMBLED VIEW OF A FULLY INCLOSED BALDOR SINGLE-PHASE REPULSION-STARTING INDUCTION-RUNNING BALL-BEARING MOTOR

Courtesy of Baldor Electric Company, St. Louis, Missouri

DICTIONARY of Electrical Terms

Including Symbols, Formulas, Diagrams, and Tables.

ELECTRICAL SYMBOLS FOR ARCHITECTURAL PLANS

CEILING WALL

GENERAL OUTLETS

- Outlet.
- Capped Outlet.
- Drop Cord.
- Electrical Outlet—for use only when circle used alone might be confused with columns, plumbing symbols, etc.
- Fan Outlet.
- Junction Box.
- Lamp Holder.
- PS Lamp Holder with Pull Switch.
- Pull Switch.
- Outlet for Vapor Discharge Lamp.
- Exit Light Outlet.
- Clock Outlet (Lighting Voltage).

CONVENIENCE OUTLETS

- Duplex Convenience Outlet.
- 1,3 Outlet other than Duplex. 1=Single, 3=Triplex, etc.
- WP Weatherproof Convenience Outlet.
- R Range Outlet.
- Switch and Convenience Outlet.
- Radio and Convenience Outlet.
- Special Purpose Outlet (see Spec.)
- Floor Outlet.

SWITCH OUTLETS

$	Single Pole Switch.
$2	Double Pole Switch.
$3	Three Way Switch.
$4	Four Way Switch.
$D	Automatic Door Switch.
$E	Electrolier Switch.
$K	Key Operated Switch.
$P	Switch and Pilot Lamp.
$CB	Circuit Breaker.
$WCB	Weatherproof Circuit Breaker.
$MC	Momentary Contact Switch.
$RC	Remote Control Switch.
$WP	Weatherproof Switch.

SPECIAL OUTLETS

a,b,c-etc.
a,b,c-etc.
$ a,b,c-etc.

Any Standard Symbol with the addition of a lower case subscript letter may designate a special variation of standard equipment. They must be listed in the Key of Symbols on each drawing

PANELS AND CIRCUITS

- Lighting Panel.
- Power Panel.
- Branch Circuit—Ceiling or Wall.
- Branch Circuit—Floor, 2-wire.
- Branch Circuit—Floor, 3-wire.
- Branch Circuit—Floor, 4-wire, Etc.
- Feeders, Heavy lines, numbered as listed in the Schedule.
- Underfloor Duct & Junction Box—Triple System. Note: For double or single systems eliminate one or two lines. This symbol is equally adaptable to auxiliary system layouts.

MISCELLANEOUS

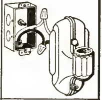
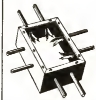
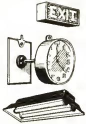
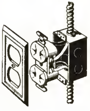
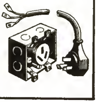
- Generator.
- Motor.
- Instrument.
- Transformer.
- Controller.
- Isolating Switch.

AUXILIARY SYSTEMS

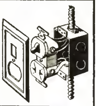
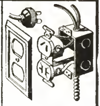
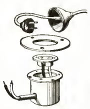
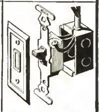
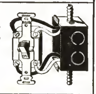
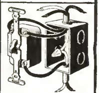
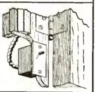
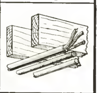
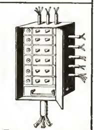
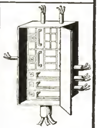
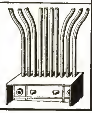
- Push Button.
- Buzzer.
- Bell.
- Annunciator.
- Telephone.
- Telephone Switchboard.
- Clock (Low Voltage).
- Electric Door Opener.
- Fire Alarm Bell.
- Fire Alarm Station.
- City Fire Alarm Station.
- Fire Alarm Central Station.
- Automatic Fire Alarm Device.
- Watchman's Station.
- Watchman's Central Station.
- Horn.
- Nurse's Signal Plug.
- Maid's Signal Plug.
- Radio Outlet.
- Signal Central Station.
- Interconnection Box.
- Battery.
- Auxiliary System Circuits. Line without further designation indicates 2-wire circuit. For a number of wires designate as: 12-No. 18W-¾″-C.; or by number as in schedule.
- a,b,c Special Auxiliary Outlets Letters refer to notes on plans or details in spec.

Courtesy of American Standards Association, New York, N. Y.

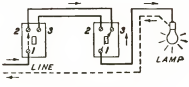
SYMBOLS USED ON ARCHITECTURAL PLANS

SYMBOL	OBJECT	SYMBOL	OBJECT
CEILING OUTLET		WALL OUTLET	
CAPPED OUTLET		DROP CORD	
FAN OUTLET		JUNCTION BOX	
LAMP HOLDER		PULL SWITCH	
EXIT OUTLET CLOCK OUTLET OUTLET FOR VAPOR DISCHARGE LAMP		DUPLEX CONVENIENCE OUTLET	
WEATHERPROOF CONVENIENCE OUTLET		RANGE OUTLET	

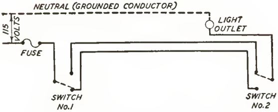
SYMBOLS USED ON ARCHITECTURAL PLANS

SYMBOL	OBJECT	SYMBOL	OBJECT
SWITCH AND CONVENIENCE OUTLET		RADIO AND CONVENIENCE OUTLET	
SPECIAL PURPOSE AND FLOOR OUTLET		\$ SINGLE-POLE SWITCH	
$\$_2$ DOUBLE-POLE SWITCH		$\$_3$ THREE-WAY SWITCH	
$\$_D$ AUTOMATIC DOOR SWITCH		FEEDERS	
LIGHTING PANEL		POWER PANEL	
CEILING OR WALL FLOOR BRANCH CIRCUIT		GENERATOR OR MOTOR	

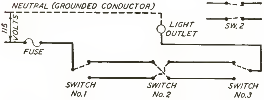
THREE- AND FOUR-WAY SWITCH CIRCUITS



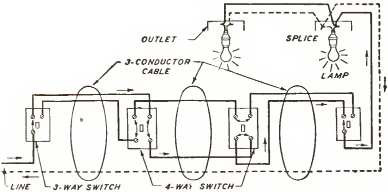
Circuit-Wiring Diagram for Three-Woy Switch Control



Wiring Diagram for Switching a Light On or Off at Two Locations

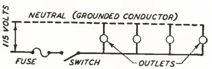


Wiring Diogrom for Switching o Light On or Off at Three Locations

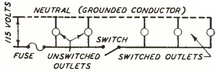


Circuit Wiring Diagram for Three-Woy and Four-Woy Switch Control from Four Ploces

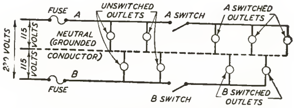
LIGHTING AND RANGE CIRCUITS



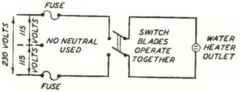
A 2-Wire 115-Volt Circuit with Outlets Controlled by Switch



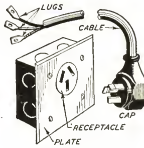
A 2-Wire 115-Volt Circuit with Switch Controlling Part of the Outlets Only



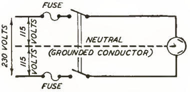
A 3-Wire Single-Phase 115/230-Volt Circuit with Part of the Outlets Controlled by Switches



Method of Switching a 2-Wire Single-Phase 230-Volt Circuit

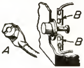
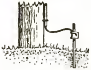
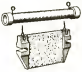
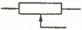
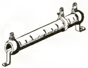
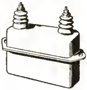
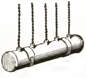
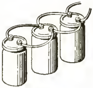
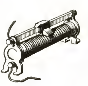
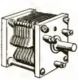
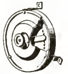
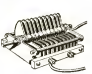
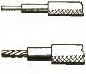
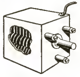


An Electric Range Receptacle and Cord

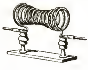
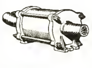
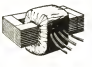
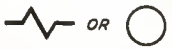
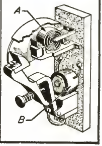


Switching on Electric Range Circuit

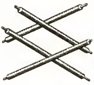
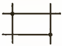
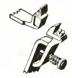
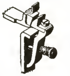
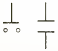
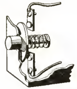
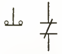
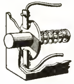
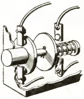
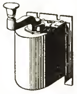
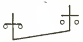
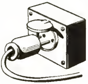
RESISTOR AND CAPACITOR SYMBOLS

SYMBOL	OBJECT	SYMBOL	OBJECT
O OR ● (A) TERMINAL STUD (B) PUSH-BUTTON CONTACT		 GROUND	
 FIXED RESISTOR		 FIXED CAPACITOR	
 ADJUSTABLE RESISTOR		 FIXED CAPACITOR, SHIELDED	
 TAPPED RESISTOR		 ADJUSTABLE CAPACITOR	
 VARIABLE RESISTOR		 VARIABLE CAPACITOR	
 RHEOSTAT		 VARIABLE CAPACITOR WITH MOVING PLATE INDICATED	
CONDUCTOR		 VARIABLE CAPACITOR, SHIELDED	

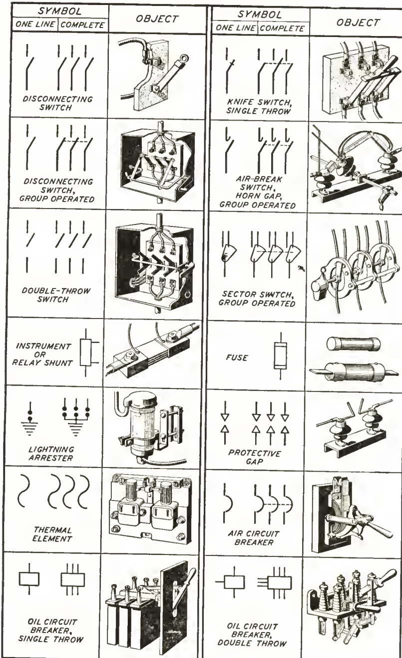
INDUCTOR, REACTOR, COIL, AND FIELD SYMBOLS

NONMAGNETIC CORE		MAGNETIC CORE	
SYMBOL	OBJECT	SYMBOL	OBJECT
 FIXED		 FIXED	
 ADJUSTABLE		 ADJUSTABLE	
 ADJUSTABLE BY TAPS		 ADJUSTABLE BY TAPS	
 VARIABLE		 (A) BLOWOUT COIL  (B) SERIES OR SHUNT OPERATING COIL	

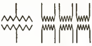
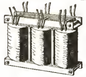
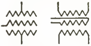
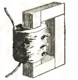
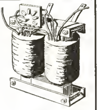
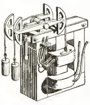
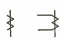
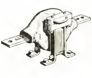
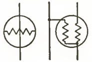
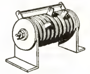
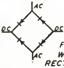
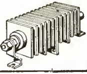
CONTACT AND PUSH-BUTTON SYMBOLS

SYMBOL	OBJECT	SYMBOL	OBJECT
 CONDUCTOR CROSSING		 CONDUCTOR CONNECTIONS	
 CONTACTS-N.O. (NORMALLY OPEN)		 CONTACTS-NC (NORMALLY CLOSED)	
 PUSH BUTTON-N.O. (SPRING RETURN)		 PUSH BUTTON-NC (SPRING RETURN)	
 PUSH BUTTON OPEN AND CLOSED (SPRING RETURN)		NO SYMBOL MULTIPOSITION SWITCH (MASTER-DRUM SELECTOR SWITCH)	
 PUSH BUTTON OPEN AND CLOSED (MAINTAIN CONTACT)		 DISCONNECT DEVICE (COUPLING OR PLUG TYPE CONTACT)	

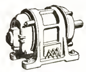
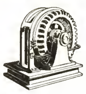
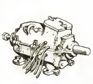
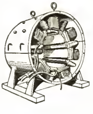
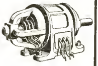
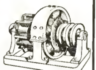
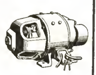
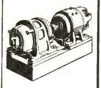
SWITCH AND CIRCUIT-BREAKER SYMBOLS



TRANSFORMER SYMBOLS

SYMBOL (ONE LINE / COMPLETE)	OBJECT	SYMBOL (ONE LINE / COMPLETE)	OBJECT
 SINGLE-PHASE TWO-WINDING TRANSFORMER		 POLYPHASE TWO-WINDING TRANSFORMER	
 THREE-WINDING TRANSFORMER		 AUTO TRANSFORMER	
 TRANSFORMER WITH TAPS		 CONSTANT CURRENT TRANSFORMER	
 CURRENT TRANSFORMER		 BUSHING CURRENT TRANSFORMER	
 INDUCTION VOLTAGE REGULATOR		 CAPACITANCE BUSHING	
 HALF WAVE DRY OR ELECTROLYTIC RECTIFIER		 FULL WAVE RECTIFIER	

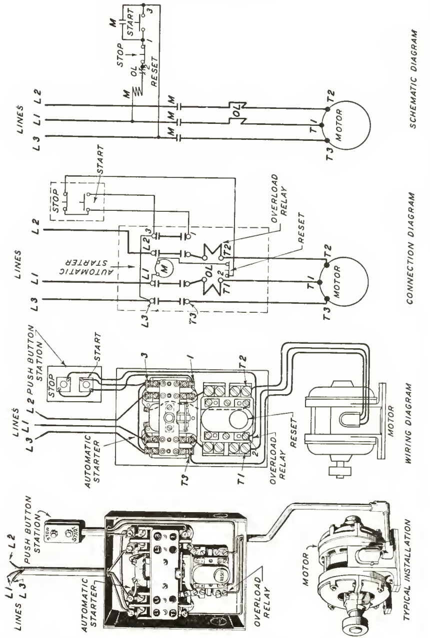
MOTOR AND GENERATOR SYMBOLS

SYMBOL			OBJECT
ONE LINE	COMPLETE		
		SQUIRREL-CAGE INDUCTION MOTOR	
		SYNCHRONOUS MOTOR OR GENERATOR	
		DIRECT-CURRENT SERIES MOTOR	
		D-C GEN. OR MOTOR WITH SHUNT, SERIES, AND COMMUTATING FIELDS	
		WOUND-ROTOR INDUCTION MOTOR OR GENERATOR	
		SYNCHRONOUS CONVERTER	
		DIRECT-CURRENT SHUNT MOTOR	
		DIRECT-CONNECTED UNITS BASIC SYMBOL	

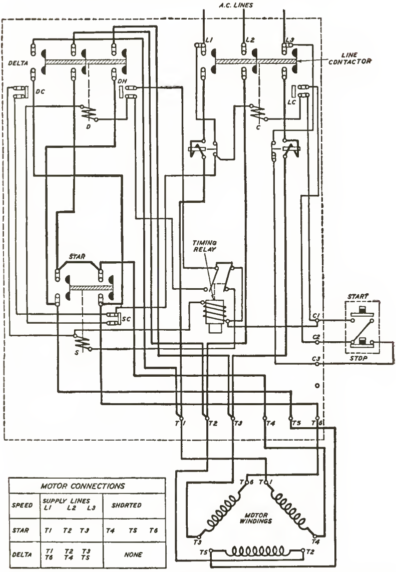
ABBREVIATIONS USED ON CONTROLLER DIAGRAMS

A .... armature acceleration
A1-A2 .... D.C. armature
AS .... armature shunt
a..... auxiliary switch (breaker) normally open
b..... auxiliary switch (breaker) normally closed
BR .... brake
BV .... balanced voltage
CF....... field forcing (increasing on variable voltage)
CR .... control relay
D .... down contactor or relay
DB .... dynamic braking
DF .... field dynamic braking
DF....... field forcing (decreasing on variable voltage)
DS .... door switch
F .... forward
FA .... field acceleration
FD .... field deceleration
FD .... field discharge
FF .... full field
F1-F2 .... D.C. shunt field
FL......... field failure (loss of field)
FLD .... final limit—down
FLF .... final limit—forward
FLH .... final limit—hoist
FLL .... final limit—lower
FLR .... final limit—reverse
FLU .... final limit—up
FP.... field protective (field weakened at standstill)
FR .... field reversing
FW .... field weakening
GF .... generator field
H .... hoist
H1-H2-H3 .... transformer primary
HS .... high speed
J .... jam
KO .... kick-off
L .... lowering
LD .... landing
L1-L2-L3 .... line
LS .... limit switch
LS .... low speed
LT .... low torque
LV .... low voltage
M .... main or line
MF .... motor field
MLD .... middle landing
M1-M2-M3-M4 .... A.C. secondary
MR .... compensator—running
MS .... compensator—starting
MS .... master switch
MT .... maximum torque
NC .... normally closed
N.O .... normally open
OL .... overload
P .... plug
PM .... pilot motor
R .... reverse
SD .... slow down
SR .... series relay
S1-S2; S-3-S4 .... series field
T .... time
TS .... thermostat
T1-T2-T3-T4 .... A.C. primary
U .... up
UV .... undervoltage
VR .... voltage relay
X1-X2-X3..... transformer secondary
1-2-3-4-5 etc. .... control terminals

ACROSS-THE-LINE AUTOMATIC STARTER INSTALLATION AND DIAGRAMS

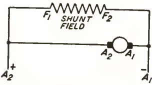


CONNECTION DIAGRAM OF AN AUTOMATIC STAR-DELTA STARTER

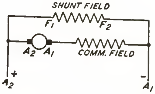


MOTOR CONNECTIONS						
SPEED	SUPPLY LINES L1	L2	L3	SHORTED		
STAR	T1	T2	T3	T4	T5	T6
DELTA	T1 T6	T2 T4	T3 T5	NONE		

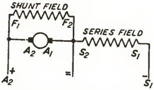
Pressing the start button allows current to flow from *L1*, through the overload trip contact and line contactor coil *C* to *C1*, across the start button and through the stop button to *C3* and the other side of the line *L3*. This closes the line contactor joining the main line *L1*, *L2*, and *L3* to the corresponding terminals *T1*, *T2*, and *T3* of the motor. Also the lock-in contact *LC* connects the line contactor coil through *C2* to the stop button, thus holding the line contactors closed when the start button is released. At the same time that the current flows through the line contactor, coil *C*, there is a flow of current from line *L1* through the interlock contacts.



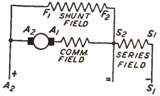
Connection Diagram of Direct-Current Shunt Generator



Connection Diagram of Direct-Current Generator with Commutating Poles



Connection Diagram of Direct-Current Compound Generator



Connection Diagram of Direct-Current Compound Generator with Commutating Poles

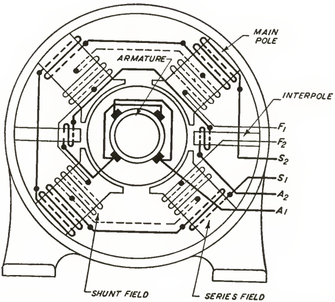
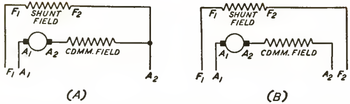
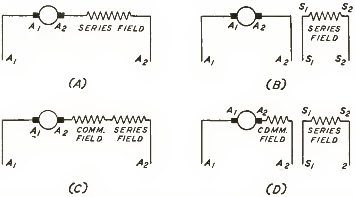


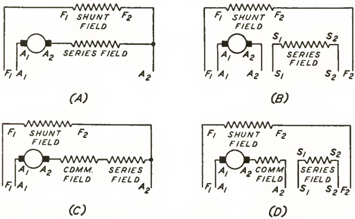
Diagram of Internal Connections of a Compound Generator with Two Interpoles



Connection Diagrams for Direct-Current Shunt Motors. (A) Nonreversing, Commutoting Pole Type; (B) Reversing, Commutoting Pole Type



Connection Diagrams for Direct-Current Series Motors. (A) Nonreversing Type; (B) Reversing Type; (C) Nonreversing, Commutating-Pole Type; (D) Reversing, Commutating-Pole Type



Connection Diogroms for Direct-Current Compound Motors. (A) Nonreversing Type; (B) Reversing Type; (C) Nonreversing, Commutoting-Pole Type; (D) Reversing, Commutoting-Pole Type

SINGLE-PHASE MOTOR DIAGRAMS

Split-phase and series universal

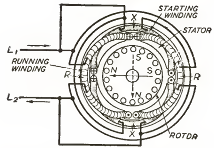


Diagram of Split-Phase Alternating-Current Motor with Starting and Running Windings

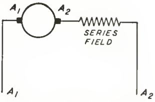


Diagram of a Single-Phase Series Universal Motor

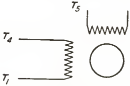


Diagram of Split-Phase Reversible Motor with Manual Cutout

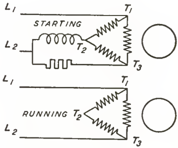
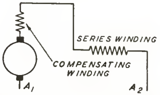


Diagram of Single-Phase Induction Motor with Starting Box

Rotation		L_1	L_2	Open
One direction	Start...	T_1 T_5	T_4 T_8	...
	Run...	T_1	T_4	T_5 T_8
Other direction	Start..	T_4 T_5	T_1 T_8	....
	Run...	T_4	T_1	T_5 T_8



Diagrom of Series Motor Conductively Compensated by Use of Separate Stator Windings

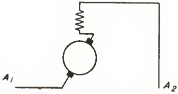


Diagram of Series Motor Conductively Compensated, Using the Same or Common Stator Windings

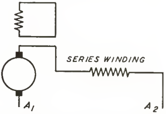
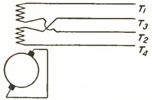


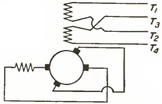
Diagram of a Series Motor Inductively Compensated by Separate Windings

REPULSION-INDUCTION MOTOR DIAGRAMS
DOUBLE VOLTAGE AND REVERSIBLE



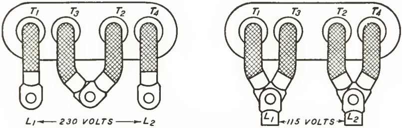
Voltage	L_1	L_2	Tie Together
Low	T_1 T_3	T_2 T_4	....
High	T_1	T_4	T_2 T_3

Diagram of a Double-Voltage Repulsion Motor and Repulsion-start Induction-run Motor



Voltage	L_1	L_2	Tie Together
Low..........	T_1 T_3	T_2 T_4	......
High	T_1	T_4	T_2 T_3

Diagram of a Double-Voltage Inductively Compensated Repulsion Motor



Method of Connecting the External Terminals of a Two-Voltage Repulsion Motor to the Supply Lines

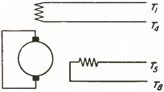


Diagram of Electrical Reversible Repulsion Motor and a Repulsion-Start Induction-Run Motor

Rotation	L_1	L_2	Tie Together
One direction ..	T_1	T_8	T_4 T_5
Other direction	T_1	T_5	T_4 T_8

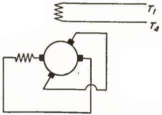


Diagram of an Inductively Compensated Repulsion Motor

TORQUE-HP FORMULA

$$\text{Torque} = \frac{\text{Hp} \times 5250}{\text{rpm}}$$

PRONY BRAKE TEST FORMULA

$$\text{Hp} = \frac{2 \times 3.1416 \times \text{Lever in ft} \times \text{lb} \times \text{rpm}}{33{,}000}$$

CENTRIFUGAL FORCE

F = centrifugal force in pounds

W = weight of revolving body in pounds

r = distance from the axis of motion to the center of gravity of the body in feet

N = number of revolutions per minute

v = velocity in feet per second

g = acceleration due to gravity (32.2 feet per second)

$$F = \frac{W\,v^2}{g\,r} = .00034\;W r\,N^2$$

Stored Energy in Flywheel

Ft-lb. energy stored in flywheel $= E = \frac{1}{2}\,(Wv^2/g)$

In which E = Ft-lbs. stored energy

W = Weight of flywheel in lbs.

v = Velocity of radius of gyration in ft. per sec.

g = Acceleration due to gravity (32.2 ft. per sec.)

HORSEPOWER OF WATERFALL

$$\text{Hp} = \frac{62 \times A \times V \times H}{33{,}000}$$

A = Cross section in sq. ft. of stream flowing over dam

V = Velocity of flow in feet per minute

H = Head of fall in feet

Dictionary of Electrical Terms

A

A.C.: Abbreviation for alternating current.

abscissa: A distance measured horizontally to the right and left of a vertical line.

absolute units: A unit of measurement which has been determined from certain physical properties and upon which all other units are based.

accumulator: A storage battery.

acid proof paint: A paint made especially to resist the action of acid.

admittance: A unit used in alternating current circuits, which is the opposite to impedance, measured in ohms.

aerial: Wires supported above ground and used for receiving or sending electrical waves.

advance wire: An alloy of copper and nickel used for electric heating units.

air blast transformer: A transformer cooled by forcing a circulation of air around its windings.

air gap: Air space between magnetic poles. Space between stationary and rotating parts of an electric motor and generator.

algebraic: Taking into account the sign used in algebra.

alive: Carrying a voltage or current.

alkaline battery: A storage battery using an alkali instead of acid for electrolyte Edison Cells.

all-day-efficiency: The total output divided by the total input of energy for the entire day.

alloy: A metal composed of two or more different metals.

alphaduct: A flexible non-metal conduit.

alternating current: An electric current that reverses its direction of flow at regular intervals.

alternation: One vibration instead of a cycle. One-half a cycle of alternating current.

alternator: An electric generator producing alternating current.

aluminum: A white metal, light in weight but having a higher electrical resistance than copper.

aluminum cell arrester: A lightning arrester using a series of aluminum plates and an electrolyte which forms a thin insulating film on the plates at normal voltage, but becoming a conductor when a high voltage, like lightning, occurs. As soon as the high voltage is reduced to normal, the insulating film is formed again.

aluminum rectifier: A jar containing aluminum plates and iron or lead plates immersed in a solution of ammonium phosphate and which will allow current to flow, though only in one direction, from the iron or lead plates to the aluminum plate.

amalgam: An alloy of mercury or quicksilver with other metals.

amber: A yellowish resinous substance that can be used to produce static electricity by friction.

American wire gauge: The gauge is used for designating the sizes of solid copper wires used in United States. Formerly called Brown and Sharpe (Best gauge).

ammeter: The instrument that indicates the rate of flow of electricity through a circuit.

ammeter shunt: A special low resistance conductor connected to the terminals of an ammeter so as to carry nearly all the current, allowing only a very small current to flow through the instrument itself.

ampere: The practical unit that indicates the rate of flow of electricity through a circuit.

ampere-hour: The quantity of electricity delivered by a current of one ampere flowing for one hour. Used in rating storage batteries.

ampere-hour meter: An instrument that registers or records the number of ampere-hours of electrical energy that have passed through a circuit.

ampere-turn: The amount of magnetism or magnetizing force produced by a current of one ampere

flowing around a coil of one turn. The product of the current flowing through a coil by the number of turns or loops of wire on the coil.

amplifier: A device by which weak currents or sounds acting on another circuit are increased in strength.

anchor: A metal placed in the ground and to which a guy wire from a pole is attached.

angle of dip: The number of degrees that one end of a magnet dips or points downward.

angle of lag and lead: The distance expressed in degrees that an alternating current lags or leads the voltage wave. The cosine of this angle is called the power factor.

anion: The ion which moves toward the anode in an electrolytic cell.

anneal: To soften by heating and allowing to cool slowly.

annunciator: An electric signal equipment having a number of push buttons located at different places which are wired to an electromagnet in the annunciator box. Press any push button and it causes a signal to be displayed showing what button was operated.

annunciator wire: A soft copper wire that has two layers of cotton threads wound on it in opposite direction and covered with paraffin wax.

anode: The terminal or electrode through which current flows into the electrolyte.

antenna: Wires arranged to receive or send out electromagnetic (Radio) waves into the air.

anti: A prefix, meaning opposite, against, opposed to, etc., to the word that follows it.

apparent E.M.F.: The apparent voltage as measured by the drop in pressure due to current flowing through the resistance.

apparent efficiency: In alternating current apparatus it is the ratio of net power output to volt-amperes input.

apparent watts: The product of volts times amperes in an alternating current circuit.

arc: The flow of electric current across a gap in a circuit which causes a light or glow.

arc furnace: An electric furnace in which heat is produced by an arc between two electrodes.

arc lamp: A lamp producing light from an arc.

arc lamp carbon: A carbon rod between which the arc is produced in an arc lamp.

arc light generator: A generator producing a constant current for an arc light circuit. Nearly obsolete.

arc welding: Joining two pieces of metal together by use of an electric arc.

argon: An odorless, colorless, inert gas taken from the air. Used in some types of incandescent light bulbs.

armature: The rotating part of a direct current motor or generator. The part of the generator that delivers electrical energy or the part of the motor that receives electrical energy from the circuit. Also a piece of iron or steel joining the poles of an electromagnet.

armature air gap: The air space between the stationary and rotating parts of a motor or generator where the magnetic lines of force pass from one to the other.

armature back ampere turns: The magnetic field produced by current flowing in the armature winding that opposes and reduces the number of magnetic lines of force produced by the field magnets of a motor or generator.

armature band: A group of wires wound closely together, or a metal band placed on the coils of the armature to hold them in place.

armature bar: Copper bars used in place of wire winding the armatures of large generators and motors.

armature bore: The space between opposite pole pieces in which the armature revolves.

armature circuit: The path that the current takes in flowing through the windings from one brush to another.

armature coil: The loop or coil of copper wire placed on the armature core and which forms part of the winding.

armature core: The laminated iron part of the armature, formed from thin sheets or disks of steel, and on which the windings are placed.

armature current: The current flowing from the armature of a generator or to the armature of a motor. It does not include the current taken by the shunt field coils.

armature disks: Thin sheets of iron or steel used in building up the armature core.

armature demagnetization: The reduction in the effective magnetic lines of force produced by the armature current.

armature reaction: The effect that the magnetism produced by the current flowing in the armature has on the magnetism (magnetic lines of force) produced by the field coils.

armature resistance: The resistance of the wire used in the windings of the armature measured between rings or brushes, or from positive to negative terminal.

armature slot: The groove or slot in the armature core into which the coils or windings are placed.

armature stand: A device for supporting or holding an armature by the shaft when it is being wound or worked on.

armature tester: Any device or instrument used for locating faults or defects in the armature winding.

armature tooth: The metal between the slots in an armature core.

armature varnish: A liquid put on the field and armature windings to improve the insulation of the cotton coverings on the wires.

armature winding: All of the copper wire placed on the armature and through which current flows when the machine is operating.

armored cable: Rubber-covered wires that have been covered with an iron, steel, or other flexible metallic covering. Often called BX.

artificial magnet: A manufactured permanent magnet, as distinguished from natural magnets.

asbestos: A mineral fiber formed from a certain rock. It is a poor conductor of heat and can withstand high temperatures. Used to insulate wires exposed to a high temperature.

astatic system: An arrangement of two parallel magnets with the north end of one pointing the same way as the south end of the other, so that the two together make a very poor compass needle.

astatic galvanometer: A galvanometer in which the moving parts are arranged in an astatic system or manner.

astatic meter: A meter in which the moving part of element is arranged in an astatic system.

asynchronous: Not having the same frequency; not synchronous; not in step or phase.

asynchronous generator: An induction generator.

asynchronous motor: An induction motor. A motor whose speed is not synchronous with the frequency of the supply line.

atmosphere: The air surrounding the earth. A pressure of 1 atmosphere is 14.7 pounds to the square inch.

atmosphere electricity: Static electricity produced in the sky or between clouds.

atom: The smallest particle or unit of matter that can be chemically united.

atomic weight: The weight of one atom of a chemical element as compared to the weight of an atom of hydrogen.

atonic interrupter: A special interrupter that can be adjusted to operate at a large number of different frequencies.

attachment plugs: A plug that is screwed into a lamp socket, connecting the two wires from an electrical appliance to the circuit.

attenutation: The weakening of an alternating current that flows along a line that has resistance and capacity or leakage.

Aurora Borealis: A light or glow sometimes seen in the northern sky on certain nights.

auto call: A device that sounds a certain code of signals in various places; in a building or factory.

auto-transformer: A transformer in which one winding or coil serves both for the primary and the secondary circuit.

automatic: A device that is operated by certain changes or conditions in an electric circuit and which is not controlled by any person.

automatic telephone: A telephone system where the connection from one party to another is made by means of automatic switches, without the aid of an operator.

automatic time switch: A switch operated at certain times by means of a clock.

automotive: Self propelled vehicles, such as automobiles, trucks, tractors and motorcycles.

automobile battery: The storage battery used in an electric vehicle. The storage battery used for starting and lighting a gasoline automobile.

automobile fuse: A small fuse used to protect the generator and lighting circuits on an automobile.

auxiliary: Extra, or something added to the main one.

auxiliary bus: A second bus that may have a different voltage from the main bus and to which a few machines are connected.

auxiliary circuit: Another circuit besides the main circuit; often a control circuit.

auxiliary switch: A switch operated or controlled by the action of another circuit.

B

b: A symbol used for "susceptance" in an alternating current circuit.

B: A symbol for magnetic flux density.

B.B.: Abbreviation for Best Best iron telephone wire.

B-battery: The radio battery that keeps the plate of an electron tube positive in relation to the filament.

B.S.G.: British Standard Gauge.

B. board: One of the switchboards in a large telephone exchange where one subscriber is connected to another.

B.t.u.: British thermal unit; the heat required to raise the temperture of 1 pound of water 1 degree F.

B.W.G.: Birmingham wire gauge. The same as Stubs' Copper wire gauge.

BX: A term often used for flexible armored cable.

B. & S.: Brown & Sharpe wire gauge which is the same as American wire gauge.

babbitt metal: An alloy of lead, tin, copper, zinc, and antimony used for bearings of electrical machines.

back pitch: The distance between the two sides of an armature coil at the back side of the armature, usually expressed in number of slots.

back ampere turns: The ampere turns on the armature that produce magnetism that opposes that produced by the field coils.

bakelite: A moulded insulating material.

balanced load: Arranging the load equally on the two sides of a three-wire system.

balancer coil: An auto transformer used to provide a neutral wire on a 3-wire system.

balancer set: Two direct current generators or motors coupled together and used to keep the voltage the same on each side of a 3-wire system.

ballastic galvanometer: A type of galvanometer used for measuring the quantity of electricity suddenly discharged through it, from usually a condenser, expressed as the angle through which the movable part turns.

bank of lamps: A number of lamps, connected either in series or in parallel, used as a resistance.

bank of transformers: A number of transformers located at one place and connected to the same circuit.

bar magnet: A straight permanent magnet.

bar windings: Windings composed of copper bars or rods instead of wire.

barometer: An instrument for measuring the pressure of the atmosphere.

barrier: A partition, slab, or plate of insulating material placed between blades of switches, wires, or conductor in order to separate or insulate them.

battery: A number of similar units arranged to work together. A number of primary or storage cells connected either in series or in parallel.

battery acid: The liquid used in a storage battery. This is usually sulphuric acid.

battery box: The box holding the cells forming the battery.

battery capacity: The amount of energy that can be obtained from a storage battery—usually expressed in ampere-hours.

battery case: A battery box.

battery charger: A rectifier used for changing alternating current into direct current for charging a battery.

battery connector: A lead covered link or bar used to connect one terminal of a cell to the terminal of the next cell of a battery.

battery discharger: An adjustable resistance used to test the condition of the battery by discharging the battery.

battery hydrometer: A hydrometer used for testing the specific gravity or density of the electrolyte in a storage battery.

battery oven: An oven into which storage batteries are placed and heated in order to soften the compound that seals the cover to the battery cells.

battery paint: A paint, that will resist the action of acids, used to paint the battery boxes or battery rooms.

battery resistance: The internal resistance of a cell or number of cells. The resistance of the plates and electrolyte measured between the external terminals.

battery steamer: An apparatus used for producing steam inside a storage battery case in order to soften the sealing compound.

bayonet socket: A lamp socket that has two lengthwise slots in the sides of socket and at the bottom the slots make a right angle turn. The lamp base has two pins in it that slide in the slots in the socket. The lamp is held in the socket by being given a slight turn when the pins reach the bottom of the slots.

bearing: That part which holds or supports the shaft.

bearing bracket: That part of the machine extending outward from the frame of a machine and which supports or holds the bearings.

bearing loss: Loss of power due to the friction between the shaft and the bearing of a machine.

bearing metal: A special alloy that has the smallest amount of friction between itself and the rotating shaft. Often used as a lining in the bearing.

bell hanger's bit: A long slim wood bit used to drill through the frame of a building when installing door bells.

bell ringing transformer: A small transformer, slipping the voltage down from 110 volts to about 10 volts, used on a door bell.

B-H curve: A curve that shows the relation between the magnetizing force and the number of lines of force per square inch or centimeter produced in different metals.

Bi: A chemical symbol for bismuth.

bichromate cell: A primary cell consisting of carbon and zinc electrodes immersed in a solution of potassium bichromate and sulphuric acid.

binding posts: Terminals used on apparatus or circuits so that other circuits can be quickly attached.

bipolar: Having only two magnetic poles.

Birmingham wire gauge: Wire gauge used for measuring galvanized iron telephone and telegraph wires; also called Stubs' gauge.

block lead: A form of carbon called graphite.

blow-out coil. An electromagnet used for deflecting the arc between two contacts and thus blowing out the arc.

bond: A short high-grade conductor cable or wire used to connect the end of one rail to the next.

booster: A generator connected in series with a circuit in order to increase the voltage of that circuit.

booster converter: A machine that changes the current from alternating to direct or the opposite, that has a booster built in as part of the machine.

booster transformer: A transformer used to raise the voltage of an alternating current feeder or circuit.

box connector: An attachment used for fastening the ends of cable to a box.

braided wire: A conductor composed of a number of small wires twisted or braided together.

brake shoe: A metallic casting that bears against the wheel in order to stop the wheel from turning.

brake horsepower: The actual power of a machine measured by use of a Prony brake or dynamometer.

branch circuit: That part of the wiring system between the final set of fuses protecting it and the place where the lighting fixtures or drop cords are attached.

branch cutout: The fuse holder for the branch circuit fuse.

brazing: Uniting two metals by a joint composed of a film of brass or alloy that has a higher melting point than solder.

bridge: A Wheatstone bridge.

bridge duplex: A duplex telegraph system dependent for its operation upon the use of a Wheatstone bridge connection in which the telegraph circuit and an artificial line similar to it are the two arms.

bridging set: A telephone set designed to be connected in parallel with other telephones to a telephone line.

British thermal unit: The amount of heat required to raise the temperature of one pound of water 1 degree F.

Brown and Sharpe gauge: The gauge used in United States for copper wires. Same as American wire gauge.

bronze: An alloy of copper and tin.

brush: A conductor that makes connection between the rotating and stationary parts of an electrical machine.

brush discharge: A faint glowing discharge at sharp points from a conductor carrying high voltages. It occurs at a voltage slightly less than that required to cause a spark or arc to jump across the gap.

brush holder: The device used to hold or guide the brushes against a commutator or slip ring.

brush holder cable: A stranded conductor composed of a large number of copper wires, smaller in size than those used on regular stranded cables.

brush holder spring: A spring used to press the brush against the commutator or slip ring.

brush holder stud: An insulated bolt or rod to which the brush holders are fastened.

brush lag: The distance that the brushes on a motor are shifted against rotation in order to overcome the effect of armature reaction.

brush lead: The distance that the brushes on a generator are shifted with rotation in order to overcome armature reaction.

brush pig-tail: A short braided wire fastened to the brush. It conducts the current from the brush holder to the brush.

brush rocker: A support for the brush holders and studs arranged so the location of the brushes can be shifted around the commutator.

brush yoke: Iron framework or support for the brush holders.

bucking: One electrical circuit or action opposing another one.

buckling: Warping or twisting of storage battery plates due to too high a rate of charge or discharge.

bulb: The glass inclosing part of an incandescent lamp that surrounds the filament.

Bunsen cell: A primary cell using zinc and graphite electrodes.

burn out: Damage to electric machine or conductors caused by a heavy flow of current due to short circuit or grounds.

burning rack: A frame for holding storage battery plates when connectors or straps are being fastened to them.

bus: A contraction for bus bar.

bus bar: The main circuit to which all the generators and feeders in a power station can be connected.

bushing: An insulating tube or sleeve protecting a conductor where it passes through a hole in building or apparatus.

butt joint: A splice or connection formed by putting the ends of two conductors together and joining them by welding, brazing, or soldering.

buzzer: A door bell with the hammer and gong removed.

B-X cable: Trade name for armored cable made by General Electric Co. commonly used to refer to armored cable.

C

C: When used with temperature, refers to centigrade thermometer.

C: Capacity of condenser, usually expressed in farads or microfarads.

Cd: Chemical symbol for cadmium.

C.C.W.: Counterclockwise rotation.

Ckt: Circuit.

C.G.S.: Abbreviation for centimeter gram second units—the centimeter being the unit of length, the gram the unit of weight, and the second the unit of time.

C.P.: An abbreviation for constant potential; also for candle-power of a light.

C.W.: Clockwise rotation.

cabinet: Iron box containing fuse, cutouts, and switches.

cable: A conductor composed of a number of wires twisted together.

cable box: A box which protects the connections or splices joining cables of one circuit to another.

cable clamp: A clamp used to fasten cables to their supports.

cable grip: A clamp that grips the cable when it is being pulled into place.

cable rack: A frame for supporting electric cables.

cadmium: A silvery white metal.

cadmium test: A test of the condition of the positive and negative plates of a storage battery.

calibrate: To compare the readings of one meter with those of a standard meter that is accurate.

calido: A nickel-chrome electrical resistance wire.

call-bell: An electric bell that tells a person or operator that he is wanted.

calorie: The amount of heat required to raise the temperature of 1 gram of water 1 degree centigrade.

calorizing: A process of coating a metal with a fine deposit of aluminum similar to galvanizing with zinc.

cambric tape: A cotton tape that has been treated with insulating varnish.

candelabra lamp: A small size lamp that has a smaller size screw base than the standard lamp base but larger than the miniature base.

candle: A unit of light intensity.

candle-power: The amount of light for a source as compared to a standard candle.

canopy: The exterior part of a lighting fixture that fits against the wall or ceilings, thus covering the outlet box.

canopy switch: A switch fastened to the canopy and used to turn on and off the light in the fixture.

caoutchouc: A crude rubber, known as india rubber.

capacity: Ability to hold or carry an electric charge. The unit of capacity is farad or microfarads.

capacity of a condenser:. The quantity of electricity that a condenser can receive or hold.

capacity reactance: The measure of the opposition to the passage of an alternating current through a condenser expressed in ohms.

capillary attraction: The course of the raising and lowering of the liquid in a tube above or below the surrounding liquid.

carbon: A non-metallic element or substance found in graphite, charcoal, coal, and coke.

carbon brush: A block of carbon used to carry the current from the stationary to the rotating part of a machine.

carbon contact: A contact made of carbon used where the circuit is opened frequently.

carbon disk: A piece of carbon used as a resistance in a rheostat.

carbon holder: A device for holding and feeding the carbon rods in an arc light.

carbon pile regulator: A number of pieces of carbon arranged as a rheostat to regulate the current to another circuit.

carbon resistance: A resistance formed by carbon plates or powder and arranged so that the pressure on the plates can be varied. The less the pressure, the greater will be the resistance.

carbonize: To turn some other material to carbon by fire.

carrier current: A very high frequency current used to provide the energy for transmitting a radio message.

carrying capacity: The amount of current a wire can carry without overheating.

cartridge fuse: A fuse inclosed in an insulating tube in order to confine the arc or vapor when the fuse blows.

case-hardening: The hardening of the outside of metals with heat.

cascade connection: An electrical connection in which the winding of one machine is connected to a different winding of the next machine.

cascade converter: A rotary converter that receives its energy from the rotor (secondary) of an induction motor connected to the same shaft.

cat whisker: A fine wire spring, one end of which makes contact with a crystal in a crystal radio set.

catenary curve: The curve or sag formed by the weight of a wire hanging freely between two points.

cathion: That part of the electrolyte that tends to be liberated at the terminal when the current leaves the electrolyte.

cathode: The electrode toward which the current flows in an electrolyte. The negative electrode or terminal.

cathode rays: Those rays coming from the cathode of a vacuum tube which produce X-Rays when they strike a solid substance in the tube.

cauterize: The searing or burning of flesh with an electrical heated wire.

C.C.: An abbreviation for cubic centimeter; also **Cu c.n.** is used.

cell: A jar or container holding the plates and electrolyte of one unit of a storage or primary battery.

cell vent: An opening in the cover of a cell which allows the gasses found in the cell to escape.

celluloid: An insulating material made from gun cotton and camphor; it ignites easily and burns up very quickly.

cement: A material used to bind substances together.

cementation: The forming of lead sulphate in small quantities on storage battery plates when they are drying after being made.

center of distribution: A point near the center of the area or section served by a feeder or circuit from a power station or substation. The feeder is usually run directly to this point, and then branches out in all directions from there.

centigrade: A thermometer whose scale is 0 at the freezing point and 100 at the boiling point of water.

centimeter: The one-hundredth part of a meter; 0.3937 inches, or longer than ⅜ of an inch.

central: A telephone office or exchange.

central station: A power plant supplying electric light and power to a number of users.

centrifugal cutout: A switch opened by centrifugal force of a rotating body and closed by a spring when the centrifugal force is reduced.

centrifugal force: The force that tends to throw a rotating body, or weight, outward and away from the center of rotation.

chain winding: A type of armature winding which resembles a chain.

characteristic: A curve that shows the ability of a machine to produce certain results under a certain given condition.

charge: That quantity of static electricity stored between the plates of a condenser.

charging: Sending electric current through a storage battery.

charging rate: The number of amperes of current flowing through a storage battery when it is being charged.

choke coil: A coil of a low ohmic resistance and a high inductance which will hold back unusual currents but allow regular steady currents to flow through easily; also reactors or reactance coils.

circuit: The path taken by an electrical current in flowing through a conductor from one terminal of the source of supply to the other.

circuit breaker: A device used to open a circuit automatically.

circular loom: A flexible non-metallic tubing slipped over rubber covered wires for additional insulation and protection.

circular mil: The area of a circle one-thousandth of an inch in diameter; area in circular mils = diameter, in mils, squared or multiplied by itself.

Clark cell: A primary cell that produces a constant voltage for several years and used as a standard source of voltage.

cleat: Piece of insulating material used for fastening wires to flat surfaces.

climber: A sharp steel spur or spike fastened to the shoe and legs of linemen to aid them in climbing poles.

clockwise rotation: Turning in the same direction as the hands of a clock; right-handed rotation.

closed circuit: A complete electric circuit through which current will flow when voltage is applied.

closed circuit battery: Primary cells that will deliver a steady current for a long time. A battery that can be used on a closed circuit system.

closed coil armature: The usual armature windings in which the connection of all coils forms a complete or closed circuit.

closed magnetic circuit: A complete magnetic path through iron or other metal without an air gap.

cluster: A lighting fixture having two or more lamps on it.

cobalt: A white metal similar to nickel.

code: A series of long and short sounds given in order to convey certain signals or information.

coefficient of expansion: The increase in length of a rod or body for each degree that the temperature is increased.

coherer: A device used in the early days of radio to detect radio signals.

coil box: A box containing ignition or induction coils.

coil pitch: The number of slots spanned by an armature coil.

collector ring: A metal ring fastened to the rotating part of a machine, and completing the circuit to the rotating part of the machine.

combination fixture: A fixture arranged for both gas and electric lights.

combination switch: A switch on automobiles used to control both lights and ignition.

commercial efficiency: The ratio of total output to input of power.

commutating machines: Generator, motors, and rotary converters that have commutators.

commutating pole: An interpole placed between the pole pieces of a dynamo in order to reduce sparking at the brushes.

commutating pole rectifier: A rotary converter fitted with interpoles.

commutation: Changing the alternating current produced in the armature windings into direct current by use of the commutator and brushes.

commutator: A device by which alternating current produced in a generator is changed into direct current. It consists of a ring made up of a number of copper bars or segments; each bar is insulated from the next one and connected to the end of the armature windings.

commutator bar: A small piece of copper used in building a commutator; a commutator segment.

commutator cement: An insulating substance used in repairing or replacing mica in a commutator.

commutator compound: A compound applied to the surface of a commutator to assist in obtaining a smooth polish.

compass: A small magnetized needle pivoted at the center and pointing in a north and south direction, which is in line with the earth's magnetism, unless influenced by stronger magnets.

compensated machine: A motor or generator with a series field winding placed in slots in the face of the pole piece.

compensated voltmeter: A voltmeter connected with the bus bars at a power station. It indicates the voltage in the feeders, showing the actual pressure furnished at the far end of the circuit.

compensated winding: A winding which is placed in slots cut in the face of the pole pieces parallel with the armature slots. The current in this winding flows in the opposite direction to that in the armature slots.

compensator: A name that is applied to any device which offsets or equalizes in its effect some undesired effect.

component: A part of any thing; used in reference to the analyzing of a current in a circuit by vectors.

composite line: A telephone or telegraph line composed partly of underground and partly of overhead open wires. A line that telegraph and telephone messages may be sent over at the same time.

compound field winding: A winding composed of shunt and series coils either acting together or against each other.

compound generator: A generator that has shunt and series field coils acting together to produce a steady voltage.

compound magnet: A permanent magnet built up from a number of thin magnets of the same shape.

compound motor: A motor that has shunt and series field coils or windings.

concentrated acid: Pure acid that must be diluted before it can be used.

concentric cable: A number of wires wound spirally around and insulated from a central conductor or cable.

condenser: Two conductors separated by an insulating material that is capable of holding an electrical charge.

condenser capacity: The amount of electrical charge that a condenser will hold, measured in microfarads.

condenser dielectric: Insulating material between condenser plates or conductors.

condenser plate: One of the conductors forming the condenser.

condensite: A kind of moulded insulation.

conductance: The ease with which a conductor carries an electric current; it is the opposite of resistance. The unit of conductance is the mho (word "ohm" spelled backward).

conductivity: The ability of a substance to carry an electric current.

conductor: A wire or path through which a current of elecricity flows; that which carries a current of electricity.

conduit: A pipe or tube, made of metal or other material, in which electrical conductors or wires are placed.

conduit box: An iron or steel box located between the ends of the conduit where the wires or cables are spliced.

conduit bushing: A short threaded sleeve fastened to the end of the conduit inside the outlet box. Inside of sleeve is rounded out on one end to prevent injury to the wires.

conduit coupling: A short metal tube threaded on the inside and used to fasten two pieces of conduit end to end.

conduit elbow: A short piece of conduit bent to an angle, usually to 45 or 90 degrees.

conduit rigid: A mild steel tubing used to inclose electric light and power wires.

conduit rod: A short rod which is coupled to other rods and pushed through the large conduit to remove obstructions and pull a cable into the conduit.

conduit wiring: Electric light wires placed inside conduit.

condulet: The trade name for a number of conduit fittings made by Crouse-Hinds Co.

connected load: The sum of the rating of all the lamps, motors, heating devices, etc., connected to that circuit.

connecting-up: The process in making splices and connections to complete an electric circuit.

connector: A device used to connect or join one circuit or terminal to another.

connector switch: A device in an automatic telephone exchange that makes connection with the desired line.

consequent pole: A magnetic pole produced by placing together or near each other two north or two south poles. The forming of a pole along a magnet as well as at the ends.

consonant: A condition in a transformer which produces resonance in the primary circuit due to a certain combination of capacity and reactance in the secondary circuit. A condition to be avoided except in radio work.

constant current: A current whose amperage is the same all the time.

constant-current circuit: A series circuit, such as a street lighting circuit.

constant-current generator. A generator in which the voltage is increased as the load increases while the current is kept constant.

constant-current motor: A motor designed to operate on a constant-current circuit.

constant - current transformer: A transformer whose secondary delivers a constant alternating current, usually to a series street lighting circuit. The primary is connected to a constant-potential circuit.

constant potential: A constant voltage or pressure in the usual power and light circuit.

constant-potential generator: A generator that produces a constant voltage even though the speed is varying or changing.

constant- potential transformer: A transformer used on a constant-potential circuit.

constant-speed motor: A motor that runs at the same speed when carrying a full load as when lightly loaded.

constant-voltage regulator: A regulator that causes a generator to produce a steady voltage at varying loads.

contact: A place where a circuit is completed by a metallic point being pressed against a conductor. When the pressure is removed, the circuit is opened and flow of current stopped.

contact drop: The voltage drop across the terminals of a contact.

contact resistance: The resistance in ohms across the contact points.

contact sparking: The spark or arc formed at the contact points when a circuit carrying current is opened.

contactor: A device used to open and close an electrical circuit rapidly and often.

continental code: A series of dot and dash signals generally used in radio work to send telegraph messages.

continuous current: A direct current that is free from pulsations.

continuous rating: The output at which a machine can operate continuously without overheating or exceeding a certain temperature.

contractor: One who agrees to do a certain job for a sum of money agreed upon before the work is started.

control switch: A small switch used to open and close a circuit which operates a motor or an electromagnet coil. This motor or electromagnet is used to operate or control some electric machine.

controller: A device that governs or controls the action of electrical machines connected to it.

controller resistance: The resistance used with a controller to start and vary the speed of the motor.

converter: A machine that changes electric current of one kind into current of another kind by the use of rotating parts.

conveyors: Mechanical devices used to carry material from one place to another.

Coolidge tube: An X-ray tube first developed by Wm. D. Coolidge.

copper: A metal used for electrical conductors because it has less resistance than any other metal except silver.

copper bath: An electrolyte composed of copper salts or crystals used for copper plating.

copper clad: Iron or steel wire covered with a layer of copper in order to increase the conductivity

copper loss: The I^2R loss in power due to the resistance of the copper conductors or wires.

copper plating: Depositing a layer of copper or other metals by the electroplating process.

copper ribbon: A thin bar or strip of copper.

copper strip: A long thin bar of copper, usually about $\frac{1}{16}$ to ⅜ of an inch thick.

cord: Two insulated flexible wires or cables twisted or held together with a covering of rubber, tape, or braid.

core: The iron or steel in the center of a coil through which magnetic lines of force pass.

core iron: Iron sheets used for making cores of magnets, transformers, generators, and motors.

core loss: The power lost in a machine due to eddy currents and hysteresis losses.

core transformer: A transformer with the windings placed on the outside of the core.

corona: A violet light glow that occurs on high voltage conductors just before the voltage becomes high enough to cause a spark or arc.

corrosion: The rusting of iron and a similar action and deposit formed on other metals.

cotton-covered wire: A wire covered with a layer of thin cotton threads wound spirally around it.

cotton-enameled wire: An enameled insulated wire covered with a layer of cotton threads.

cotton sleeving: A woven cotton sleeve or tube slipped over wires to insulate them.

coulomb: The quantity of electricity passing through a circuit. It is equal to amperes times seconds. An ampere hour = 3600 coulombs.

counter-clockwise rotation: Turning left handed, which is in a direction opposite to that of the hands of a clock.

counter-electromotive force: The voltage or pressure that opposes the normal voltage tending to force a current through a circuit.

cowl lamp: A lamp placed on the dashboard of an automobile to light the instruments on it.

creeping of wattmeter: A slow turning of the wattmeter disk when there is no power passing through it.

Crookes' tubes: Tubes used for producing X-rays.

cross arm: An arm fastened at the top of the pole to support the wires.

cross magnetization: The magnetic lines of force produced in the armature that are at right angles to those produced by field coils.

cross over: A device that enables one wire to cross over another or a car to pass from one track to another parallel one.

cross-section area: The surface of the end of a wire, rod, or other object. It is measured in square inches, square centimeters, square mills, etc.

crow foot: A small fitting fastened in an outlet box to which fixtures are fastened.

crow-foot zinc: A zinc plate having extending arms, used in a gravity cell.

current: The flow of electricity through a circuit.

current coil: The coil or winding through which the current in a circuit flows.

current density: The number of amperes per square centimeter or square inch of cross sectional area of the conductor.

current regulator: A device that regulates or limits the flow of current through a circuit.

current strength: The flow of current in amperes.

current transformer: A transformer in which the flow of current in the secondary winding is in proportion to that flowing through the primary circuit, also called series transformer.

cut-in: A device operating in an electric circuit which connects two circuits together.

cut-out: A device that opens or disconnects one circuit from another.

cut-out box: The box in which fuse holder blocks, and fuses are located.

cycle: The flow of alternating current first in one direction and then in the opposite direction in one cycle. This occurs 60 times every second in a 60-cycle circuit.

D

D.C.: Used as an abbreviation for "direct current." Used as an abbreviation for "double contact."

D.C.C.: Used as an abbreviation for "double cotton-covered wire."

D.P.: Used as an abbreviation for "double pole."

D.P.S.: Used as an abbreviation for "double pole snap switch."

D.P.S.T.: Used as an abbreviation for "double pole single throw."

D.P.D.T.: Used as an abbreviation for "double pole double throw."

damper winding: As applied to copper pieces so placed in the pole faces of alternating-current machines as to reduce hunting.

damping: Causes the needle of an electric measuring instrument to come to rest quickly.

damping coil: Used to cause the needle of a galvanometer to quickly return to zero.

damping magnet: Any magnet used to check the motions of a moving object or magnet.

Daniel cell: A primary electric cell, using copper and zinc for electrodes, used on closed circuit work.

D'Arsonval meter: A voltmeter or ammeter whose pointer is attached to a moving coil of fine wire carried between the poles of a permanent magnet.

dashboard instruments: Ammeter, voltmeter, or current indicator, suitable for mounting on the dashboard or cowl board of an automobile.

dash pot: A cylindrical chamber containing oil, air, or other fluid in which moves a plunger attached to some part in which it is desired to avoid sudden changes of position.

dead beat: An instrument whose pointer comes immediately to its true reading without swinging back and forth.

dead coil: An armature coil which is not connected in the armature circuit of the windings but which is required in order that there may be the proper number of coil sides in each slot.

dead end: The end of a wire to which no electrical connection is made. The end used for supporting the wire. The part of a coil or winding that is not in use.

dead end eye: A metal eye threaded at one end to attach to a rod and holding a cable in the loop of the

dead ground: An accidental ground of low resistance through which most of the current can escape from a circuit.

dead man: A short pole with crossarms to which the guy wire from another pole is fastened.

dead wire: A wire in which there is no electric current or voltage.

decade bridge: A Wheatstone bridge having ten separate coils of equal resistance value.

deci: Is a term meaning one-tenth.

deci-ampere: One-tenth of an ampere.

declination: The difference between the position of a compass needle and the true position of geographical north and south.

declinometer: An instrument for measuring the declination of a compass needle.

de-energize: To stop current from flowing in a circuit or an electrical part.

deflection: The movement of the indicating pointer of an electric measuring instrument.

deflection of compass needle: The movement of a needle from a point of repose either in the earth's magnetic field or in that of another magnet and produced by the influence of the flux of an electric current or of a magnet.

deka: A prefix meaning ten times.

deka ampere: Ten amperes.

delivered power: The power delivered at one end of a line, in a system of electrical transmission in contradistinction to the power delivered into the line at the other end.

delta connection: Series hookup of three circuits of an alternator, the end of one circuit being connected to the beginning of the next, etc. The wiring diagram of this arrangement resembles a triangle or the letter Delta of the Greek alphabet.

demagnetization: Process of removing the magnetism from a magnetized substance. This may be done either by heating to a red heat, by violent jarring, or by holding the magnetized substance in and then gradually removing it from the magnetic field of a solenoid operated on an alternating current.

demagnetizing armature turns: Inductors of an armature, which, while moving in the field of the poles, set up a counter-magnetic field that tends to demagnetize the poles.

demand: Amount of electric current needed from a circuit or generator.

demand factor: Ratio of the maximum amount of current consumed in one sub-circuit to the total load or current draw on the whole circuit.

demand meter: Device which registers the maximum ampere consumption of appreciable duration in a circuit.

density: The ratio of a quantity of a substance to the space it occupies; i.e., the ratio of mass to volume.

density of current: Amount of current flowing through a conductor of given cross-sectional area.

density of field: Amount of magnetic flux, or lines of force, contained in a given cross-sectional area.

density of electrolyte: The proportion of chemical in the water with which it is mixed to make an electrolyte. See "specific gravity."

depolarize: (a) To eliminate or retard the gas which tends to collect on the electrodes of an electric cell when it is being charged or discharged. (b) Synonym for demagnetize.

depolarizer: A chemical, electrochemical, or mechanical agent introduced into the cell to prevent or retard the formation of gas which polarizes the electrodes.

derived circuit: Shunt or parallel circuit, the current for which is obtained from another circuit.

deviation factor: Difference between an alternating-current wave of a generator and a true sine wave.

diamagnetic substance: One that is repelled by a magnet, as bismuth and phosphorus.

diaphragm: A disk or sheet of metal or other substance having enough flexibility to vibrate, as a telephone-receiver diaphragm.

dielectric: Insulation between conductors of opposite polarity; term generally used only when induction may take place through it.

dielectric constant: A number representing the dielectric quality of a given substance as compared to that of air.

dielectric current: Leakage of current through a dielectric.

dielectric hysteresis: Consumption of energy caused by molecular friction in a dielectric under changes of electrostatic pressure.

dielectric resistance: Resistance of a dielectric to electrical pressure.

dielectric strain: Strain to which a dielectric is subjected while it is under electrical pressure.

dielectric strength: Ability of a dielectric to withstand electrical pressure before breaking down. This is measured in volts necessary to puncture the dielectric.

dies (pipe): Tools for cutting and threading metal conduit.

difference of potential: Difference in voltage between two conductors or two points along one conductor carrying an electric current.

differential booster: Generator in a battery-charging arrangement to maintain a constant voltage.

differential electromagnet: An electromagnet having part of its winding reversed to oppose the other part to permit adjustment of the pull.

differential field winding: Field winding in which the shunt and series windings of a compound-wound motor or generator oppose each other.

differential galvanometer: Galvanometer having two coils wound to counteract each other.

differential generator: Generator in which the shunt and series field windings counteract each other to limit the maximum amperage.

differential motor: A direct-current motor having its shunt and series field windings opposing each other, to obtain a constant speed.

differential relay: A relay consisting of a differential electromagnet.

differential winding: Coil which is wound opposite to another to counteract it.

diffusion of magnetic flux: Deviation of the magnetic lines of force from a straight path between the poles.

dimmer: A resistance coil connected in series with a lamp to reduce the amount of current flowing through it, and consequently to dim or reduce the light.

dinkey: Small, two-wheeled cart used for hauling poles in line construction.

dip: Angle which a magnetic needle, pivoted in a vertical plane, makes with the horizontal.

dipping needle: Magnetized needle pivoted freely at its center of gravity in a vertical plane so that, when set in a magnetic meridian, it dips until it lies parallel to the magnetic lines of force of the earth.

diphase generator: Generator producing two alternating currents a quarter of a cycle apart.

diplex telegraphy: Transmission of two telegraphic messages over the same wire, at the same time, and in the same direction.

direct-connected: Two electrical machines, such as a motor and a generator, connected together mechanically and in line, by having their shafts coupled together or by both being mounted on the same shaft.

direct current: Electric current flowing over a conductor in one direction only. Abbreviation d.c.

direct-current convertor: Device for changing a direct current of one potential to a direct current of another potential.

direct-current generator: Generator that delivers direct current.

direct-current instrument: Device operated on direct current.

direct-current magnet: Electromagnet operated on direct current.

direct-reading galvanometer: A galvanometer provided with a scale so calibrated that the current flow may be read directly, without the necessity of calculating it from the proportions of the coil and the magnetic moment of the needle.

disc armature: Armature of a generator consisting of a flat disc on which the coils are mounted.

discharge: Removal of electricity from its source through a circuit.

discharge recorder: Device which detects and records discharges through a lightning arrestor.

discharge resistance: Resistance coil which is connected across a circuit breaker to prevent arcing when the contacts separate.

discharger: Resistance device which is connected across the terminals of a storage battery to discharge it slowly without damaging it.

disconnect: To remove an electrical device from a circuit, or to unfasten a wire, making part or all of the circuit inoperative. The word is particularly applied to the act of severing a telephone connection to permit repairs.

disconnector: Switch for cutting out circuits having high voltages, done only under a minimum load.

displacement current: Small current of electricity in a dielectric which is under strain of a high potential.

disruptive discharge: Violent discharge of electricity accompanied by a spark.

dissonance: Lack of consonance or agreement; as of alternating currents of opposite phase.

dissociation: Separation of the component elements of a chemical mixture or compound, without the aid of any other chemical agency.

distortion of field: A condition causing magnetic flux between the poles of a magnet to assume an arched or curved path instead of a straight one from pole to pole.

distribution box: Small metal box in a conduit installation, giving accessibility for connecting branch circuits.

distributing frame: Structure where connections are made between the inside and outside wires of a telephone exchange.

distribution: Division of current between the branches of an electrical circuit.

distribution lines: The main feed line of a circuit to which branch circuits are connected.

distribution center: Point along the main feed lines which is approximately in the center of the branch lines.

distribution panel: Insulated board from which connections are made between the main feed lines and branch lines.

distribution system: The whole circuit and all of its branches which supply electricity to consumers.

distributive: Tending or serving to distribute.

divided circuits: Approximate division of a distribution system to balance both sides of the lines. A divided magnetic circuit is one having more than one path through which the flux passes.

dome lamp: Small lamp attached to the underside of the top of an automobile.

door lamp: Small lamp for lighting the doorway and running board of an automobile.

door lantern: Lamp hung so as to illuminate the entrance of a house.

door opener: Motor-driven device for opening and closing garage doors.

door switch: Switch which is operated by opening and closing the door to which it is connected.

double armature: An armature which has two separate windings on one core.

double-break switch: Switch which connects and disconnects two contacts at the same time.

double-contact lamp: Lamp with a base having two terminals to which electrical contact is made when it is inserted in a socket.

double-cotton-covered: Wire covered with two layers of cotton insulation. Abbreviation d.c.c.

double-current generator: A generator delivering both direct and alternating current.

double deck: Arrangement of two electrical machines, one mounted above the other.

double delta connection: Connection of three transformers by which a 3-phase system is connected to a 6-phase system.

double-filament lamp: Lamp having two separate filaments of different resistances to provide low and high brilliancy.

double-pole: A term designating two contacts or connections on a device, for instance, a double-pole knife switch. Abbreviation d.p.

double reduction: Speed reduction in a machine obtained by using two sets of gears or pulleys.

double-silk-covered. Wire covered with two layers of silk insulation. Abbreviation d.s.c.

double-throw switch: Switch which can be operated by making contact with two circuits. Abbreviation d.t.

double trolley: Street-railway system using two overhead trolleys instead of one, carrying the positive and negative current. This arrangement eliminates electrolysis caused by grounding one conductor, but it increases trolley troubles, and for this reason is seldom used.

double re-entrant winding: Armature winding, half the conductors of which make a closed circuit.

draft: Air drawn or forced up into the fire-box to accelerate fuel combustion.

draft tube: Tube or passage through which the discharge from a hydraulic turbine flows into the tailrace.

draw bar: Bar on a locomotive which is used to connect it to a train.

draw-bar pull: Force available at the draw bar of a locomotive to pull a train, as distinguished from the actual power of the engine or motor.

drive shaft: Shaft employed to drive a number of machines. Line shaft.

driven pulley: A pulley to which movement is imparted by means of a belt from another pulley.

driving pulley: Pulley that drives another through the medium of a belt.

drop: Usual term for drop of potential.

drop annunciator: Annunciator having one or more electromagnets, each of which, when operated, releases a catch holding a small plate or shutter, and allows it to drop, exposing a number or letter.

drop of potential or voltage: Decrease of voltage at points along a circuit, caused by resistance.

drop wire: Wire which is connected to a feed wire outside of a building, and brings the supply inside.

drum: The laminated iron cylinder or core of an armature for a generator or motor.

dry battery: A number of dry cells connected together in series or parallel to obtain more voltage or amperage, respectively.

dry cell: A primary source of electric current consisting of three elements; a zinc cylinder, a paste electrolyte and a carbon rod or electrode. The zinc cylinder is filled with the electrolyte and the carbon electrode is placed in the center but not touching the zinc; the top of the cell is sealed with a wax compound. The chemical action of the electrolyte on the zinc sets up an electric current when the cell is connected to a current-consuming device, as a bell. The carbon electrode is the positive and the zinc is the negative.

dry storage: Method of keeping a storage battery, when not in use, by removing the electrolyte.

dual ignition: Ignition system for an internal combustion engine which may obtain current from either a battery or a magneto as desired.

dual magneto: Ignition magneto which has its armature wound so that it can deliver both its own current and that of a battery to the distributor.

duct: (a) A space in an underground conduit to hold a cable or conductor. (b) A ventilating passage for cooling an electrical machine.

duct-foot: Unit expressing the total length of all the cableways in one lineal foot of an underground conduit. Thus, a 6-duct conduit, one foot long, contains 6 duct feet.

duo-lateral coils: Form of honeycomb inductance coils used in radio, which are designed to reduce the distributed capacity.

duplex cable: Cable consisting of two wires insulated from each other and having a common insulation covering both.

duplex ignition: Ignition system capable of sending both the battery and the magneto current into the induction coil at the same time.

duplex telegraphy: Telegraph circuit permitting the transmission of two messages in opposite directions at the same time over a single wire.

duplex winding: Two separate windings on the same armature or coil.

duplex wire: Same as duplex cable.

dynamic braking: Method of stopping a motor quickly without the aid of a mechanical brake. On d.c., a resistor connected across the armature changes the electrical energy produced by the motor, which acts as a generator when the line circuit is broken, into heat. On polyphase a.c. motors this method of braking is obtained by energizing one phase winding with direct current.

dynamic electricity: Electricity in motion as distinguished from static electricity.

dynamo: A synonym for generator; formerly applied to both motor and generator, although modern use tends to confine its meaning to d.c. generators.

dynamometer: Mechanical or electrical device for measuring the torque of a machine in order to determine its power output.

dynamotor: Electrical machine which acts as both motor and generator, running on and producing either direct or alternating current. It has one field and two separate armatures or a double-wound armature.

dyne: Unit of force. Power or force required to cause an acceleration of one centimeter per second to a mass of one gram.

E

E: Symbol for volts.

EBB: Abbreviation for "extra best best" iron wire used for telephone and telegraphic purposes.

E.C.&M.: Trade name for electric-control equipment, lifting magnets, etc.

E.H.P.: Abbreviation for electrical horsepower.

E.M.F.: Abbreviation for electromotive force.

E.P.C.: Abbreviation for Electric Power Club.

ear: Device for supporting a trolley line; a bronze casting grooved to receive the trolley and having lips which are clinched around it. The ear is supported on a trolley hanger.

earth: Synonym of "ground," meaning the grounded side of an electrical circuit or machine.

earth current: Current passing through the ground.

ebonite: Substance consisting of black hard rubber and sulphur. It is hard and brittle, has high insulating qualities, and possesses inductive qualities to a high degree.

economizer: Device used on boilers to absorb the heat that has passed the flues and would be wasted out of the stack; used to preheat boiler feed water.

eddy-current loss: Loss of energy of an electrical machine which is caused by eddy currents.

eddy currents: Currents in armatures, pole pieces, and magnetic cores, induced by changing electromotive force. It is wasted energy and creates heat.

Edison battery: Storage battery having plates made of nickel peroxide and iron, and using potassium hydrate and water for an electrolyte.

Edison distributing box: Box used in three-way distribution systems.

Edison-Lalande cell: Primary electric cell having electrodes made of copper oxide and zinc and using a caustic soda solution as an electrolyte.

"Ediswan" or bayonet socket: Lamp socket having a bayonet base, which is popular on automobile-lighting systems, and is used for house lighting in England.

"Ediswan" connector: Plug connector having a base similar to that of an "Ediswan" socket.

effective current: Value of a current as shown on a steady-reading ammeter.

effective electromotive force: Difference between the impressed and the counter e.m.f.

effective resistance: All electrical and inductive losses of a current.

efficiency: The ratio of the amount of power or work obtained from a machine and the amount of power used to operate it.

elastance: Inability or opposition to retaining an electrostatic charge. Opposite to capacity.

elastivity: Specific elastance of a substance.

elbow: Hollow fixture for connecting two lengths of conduit at an angle, usually fitted with a removable cap to facilitate drawing the wires through one conduit and then inserting them in the other one.

Electragist: Term used by the National Association of Electrical Contractors and Dealers, now the Association of Electragists, to denote a person conducting an electrical-contracting business.

electric or electrical: Pertaining to electricity.

electric circuit: Path through which an electric current flows.

electric breeze or wind: Emission of negative electricity from a sharp point of a conductor carrying a high potential.

electric candle: Small electric arc lamp.

electric charge: Quantity of electricity on a conductor.

electric eel: An eel found in South American waters which is capable of giving off painful and dangerous shocks of high potential, estimated equal to the combined charge of 15 Leyden jars, each having 1 2/3 square feet of tinfoil coating.

electric energy: Power of electricity to perform work, mechanically or in the production of heat and light.

electric furnace: Furnace using electricity to produce heat.

electric glow: electrostatic discharge causing a violet light around conductors carrying high potentials, occurring just before the emission of a spark or a steady brush discharge.

electric heater: Heater consisting of resistance wire which becomes hot as the current flows through it.

electric horsepower: The equivalent of one horsepower in electrical energy, which is 746 watts.

electric potential: Pressure or voltage of electricity.

electric power plant: Installation consisting of a prime mover driving a generator to produce electricity.

electric spectrum: The component colors of an electric arc separated by means of a glass prism.

electric units: Standards of measurement of electrical properties; for instance, ampere, volt, ohm, farad, henry, etc.

electric wave: Theoretical form of movement of an electric current transmitted through air.

electric welding: Process of welding with the use of an electric arc or with heat generated by current flowing through the resistance of the work to be welded.

electrical codes: Rules and regulations for the installation and operation of electrical devices and currents.

electrical series: A list of substances which, when two are rubbed together, will produce an electrostatic charge, as silk and hard rubber.

electrical sheet: Steel or iron sheets from which laminations for electrical machines are punched.

Electrician: Person working or experimenting with electrical devices.

electricity: Invisible energy capable of moving 186,000 miles per second. Electricity is really not capable of being defined exactly, with present knowledge.

electrification: (a) Providing means to operate devices with electricity. (b) To impose a static charge.

Electrochemical: Pertaining to the interaction of certain chemicals and electricity, the production of electricity by chemical changes, the effect of electricity upon chemicals, etc.

electrochemistry: Science of electrochemical interaction.

electrodynamic: Pertaining to electricity in action.

electrodynamometer: Device for measuring the strength of an electric current by its attraction or repulsion to conductors carrying current.

electrocute: (a) To execute a criminal by electricity. (b) Persons accidentally killed by electricity are said to be electrocuted.

electrode: Either terminal of an electric source, particularly an electric cell. Also applied to the terminals of electrical apparatus applied to the human body in the treatment of disease.

electrokinetic: Pertaining to electricity in action.

electrolier: Hanging electric fixture holding lamps which can be lighted separately or all at once.

electrolier switch: Switch which controls the lamps of an electrolier.

electrolysis: Chemical decomposition caused by an electric current.

electrolyte: Chemical solution used in an electrical device which passes an electric current.

electrolytic: Pertaining to electrolysis.

electrolytic condenser: Condenser using an electrolyte as a dielectric.

electrolytic decomposition: Separation of the elements in an electrolyte.

electrolytic generator: Generator for charging storage batteries.

electrolytic interrupter: Device for rapidly interrupting or breaking up a direct current into pulsations, consisting of a cathode, generally a lead plate, immersed in a dilute solution of sulphuric acid, and an anode, which is a small platinum wire projecting into the electrolyte from a porcelain tube. Often called a Wehnelt interrupter after the inventor.

electrolytic lightning arrestor: Lightning arrestor consisting of an electrolyte, which covers two electrodes immersed in it with a film. This breaks down under a lightning discharge.

electrolytic rectifier: Device for changing an alternating current to a direct current by passing it through an electrolyte in which electrodes are immersed. The device acts as a "valve" to allow current to pass in one direction only.

electromagnet: Soft iron core having a coil wound around it through which an electric current is passed. The core is magnetized while the current flows, but is demagnetized when the current stops.

electromagnetic attraction: Attraction between opposite poles of an electromagnet.

electromagnetic brake: Brake used on car wheels and operated by electromagnets.

electromagnetic field: Space around a conductor or instrument, traversed by the electromagnetic waves set up by current in the conductor.

electromagnetic induction: Electric current set up in a conductor cutting the field of flux of an electromagnet.

electromagnetic repulsion: Repulsion between like poles of an electromagnet.

electromagnetic unit: Unit or standard of measurement of electromagnetic effects.

electromagnetic vibrator: Mechanical interrupter operated by an electromagnet.

electromagnetic wave: Form of electromagnetic energy radiated from a conductor and theoretically assuming the form of a wave. The rate of travel of these waves is approximately 186,000 miles per second.

electromagnetism: Science dealing with electricity and magnetism and their interaction.

electrometallurgy: Branch of metallurgy dealing with the use of electric currents either for electrolytic separation and deposition of metals from solutions, or with the utilization of electricity for smelting, refining, welding, annealing, etc.

electrometer: Device for measuring small voltages.

electromotive force: Electrical pressure or voltage which forces an electric current through a circuit.

electron: Electrical particle, of negative polarity.

electron theory: Theory that all matter consists of atoms which in turn comprise a positive nucleus and a number of negative electrons, which may be detached from the atom under certain conditions, leaving it positively charged.

electro-negative: Having a negative polarity.

electropathy: Science dealing with the use of electricity for medical purposes.

electrophorous: Device consisting of a disc of ebonite or similar substance, a metal plate and an insulator, used to produce an electric charge by induction.

electropism: Science dealing with the stimulation of vegetable growth by means of electricity.

electroplating: Process of covering a metal article with a metal deposit taken from an electrode and conveyed by an electrolyte in which the article is submerged.

electro-positive: Having a positive electrical polarity.

electro-receptive device: Device that receives electricity for its operation.

electroscope: Device that indicates the presence of a very small charge of electricity. It consists of a glass bottle having an electrode, which holds two strips of light foil. These attract or repel each other, depending upon the nature of the charge.

electrostatic: Pertaining to static electricity, or electricity at rest.

electrostatic capacity: Capacity to hold an electric charge, which is measured in farads and microfarads.

electrostatic field: Range around conductors, electrical machines and instruments where electrostatic effects take place.

electrostatic galvanometer: Galvanometer operated by the effect of two electric charges on each other.

electrostatic machine: Device which produces high-potential charges of static electricity by means of friction.

electrotherapeutics: Science dealing with the use of electric currents for curing diseases.

electrothermal: Pertaining to the heating effect of electric currents, and to electric currents produced by heat, as in thermo-couple.

electrotype: Metal plate used for printing. It is made by depositing metal on a form by means of electroplating.

element: (a) One of the parts to which all matter can be reduced. (b) One of the parts constituting a device, as a radio-tube element. (c) The resistor of an electrical heating device.

elevator cable: Flexible cable conveying electricity to an elevator. Also one of the cables supporting an elevator.

"Elexit": Trade name for certain standardized interchangeable fixture receptacles and plugs.

emissivity: Rate at which particles of electricity or heat are radiated from an object.

empire cloth: Cotton or linen cloth coated with linseed oil, and used as an insulator.

enameled wire: Wire having a coating or enamel baked on, which serves as insulation.

enclosed fuse: Fuse inside of a glass tube to prevent ignition of gas or dust.

end cell: One of a number of cells at the end of a storage battery, which can be cut in or out of the circuit to regulate the voltage.

end play: Distance of movement of a shaft in line with its length.

end thrust: Thrust exerted in line with the length of a shaft.

Endosmosis: The flow of a thin liquid to a denser liquid through a permeable partition.

energize: To put energy into; e.g., magnetizing an iron core of an electromagnet by passing a current through the coil.

energy: Capacity for performing work.

entrance switch: Switch to which the wires entering a building are connected.

equalizer: Connection between generators in parallel to equalize their voltage and current.

equalizing charge: Slight overcharge on a storage battery to raise the reading of the cells having the lowest specific gravity.

equator of magnet: Position halfway between the opposite poles of a magnet.

equipotential: Having the same potential.

equilibrium: State of rest or balance between two opposite forces, produced by their counter-action.

ether: Hypothetical element filling space to permit the passage of heat, light, electricity, gravity, etc., between solar bodies.

Evaporator: Heating device for evaporating water.

excite: To send a current through the field windings of a generator to set up a magnetic flux.

exciter: Small battery of generator furnishing current for the field windings of a large generator.

exciting current: Current which passes through the field windings of a generator.

extension: Length of cable or lampcord fitted with a plug and a socket to extend a lamp or other electric device further than the original point.

exploring coil: Device used for the detection of faults in underground cables. It consists of a coil and telephone receiver or head set, a current being induced in the coil at the point of leakage and causing a noise in the receiver. (b) Coil used to locate underground metals.

"Extra Best Best" iron wire: Trade name for the highest grade iron telegraph and telephone wire. Abbreviation EBB.

external circuit: A circuit entirely outside of the source of supply.

F

F: Abbreviation for frequency.

Fabrikoid: Trade name for a substitute for leather.

factor: Any one of the elements that contribute to produce a result.

factor of safety: Multiplier used in machine and structure design, designating the overload or safety capacity. E.g., a pressure vessel designed to withstand a pressure of 10 pounds per square inch may actually withstand 50 pounds per square inch, and the factor of safety is 5.

fading: Temporary diminution of signal strength in radio reception, due to atmospheric conditions.

Fahrenheit: A thermometer scale so graduated that the freezing point of water is 32° and its boiling point is 212°.

fall of potential: Drop in voltage between two points of an electric circuit.

false resistance: Resistance of counter e.m.f.

fan motor: Motor operating a fan.

farad: Unit for measuring electrical capacity. It is the capacity of a condenser which will give a pressure of one volt when a one-ampere current flows into it for one second.

farm-lighting generator: Small, gasoline-driven generator, producing current for farm light and power; usually a 32-volt and 2 or 3 kilowatt unit.

fathom: Nautical measure of length, equal to 6 feet. This unit is used to measure cables.

fault: Trouble in an electrical circuit.

fault finder: A resistance bridge for locating faults in telephone and telegraph circuits.

fault resistance: Resistance caused by a fault.

Fauré plate: Storage-battery plate consisting of a lead grid filled with paste.

feeder: Line supplying all the branch circuits with the main supply of current.

feeder box: Box into which the feeder is run for connection to a branch circuit.

fender: Device attached to street cars and other vehicles to pick up or brush aside obstacles.

ferro-manganese: Containing iron and manganese.

ferro-nickel: Containing iron and nickel.

fibre: A hard, tough insulating substance.

fibre cleats: Cleats made of fibre, used for holding conductors on flat surfaces.

fibre conduit: Insulating tubing made of moulded fibre.

field: Space occupied by the flux of a magnet.

field coil: Coil or winding around the field magnets of a generator or motor.

field discharge resistance: A resistance coil connected across the field winding of a generator permitting the winding to be discharged without a dangerous rise in voltage when the field circuit is opened by a switch. It is usually connected to a special d.p.d.t. knife switch having an auxilliary blade which connects the resistance just before the current to the winding is cut off.

field distortion: Variation of magnetic flux from the straight path between opposite poles in a generator, which is caused by armature reaction.

field flux: Space occupied by the lines of force of a generator field.

field intensity: Density of the field flux of a generator.

field magnet: The iron parts of a generator frame through which the flux of the coils concentrates.

field rheostat: A variable resistance device connected in the field circuit to control the voltage of a generator and the speed of a motor.

field winding. Coil on a field pole of a generator.

filament: Small wire in a lamp, which becomes white hot when electric current is passed through it.

film cutout: Insulating film between the two opposite wires inside of a lamp. The film burns out when the filament breaks and this permits the two wires to make contact, which provides a path for the current so that it can flow to other lamps, connected in series. These will not light unless the current passes through the defective lamp.

filters: Devices having inductance and capacity, and designed to suppress certain electrical frequencies.

fire-alarm systems: Apparatus which gives alarm in case of fire. Some of these systems consist of electrical circuits which, when closed automatically or otherwise, sound the alarm.

fire extinguisher: Devices using a liquid or powder to extinguish fire. They are used in power houses where there is danger of burning insulation on cables. Fire extinguishers used for this purpose must contain non-conducting liquids such as carbon tetrachlorid.

fish paper: Strong paper used for insulation.

fish wire: Flat, narrow, flexible, steel wire which is used to pull conductors through lengths of conduit.

fixed resistance: Non-Adjustable resistance.

fixture: Device for holding electric lamps, which is wired inside and is securely attached to the wall or ceiling.

fixture wire: Insulated, stranded wire used for wiring fixtures.

flaming arc: Arc which gives different colors due to impregnating the carbons with various salts and minerals.

flaming of arc: A flame bridging the gap between two carbons, instead of a steady arc, caused by the carbons being too far apart.

flasher: Automatic or motor-driven switch or series of switches for lighting electric signs intermittently.

flashing over: Passage of sparks from commutator segments traveling away from the brush, to the edge of the brush, which is then touching a segment adjacent to the one from which the spark originates.

flashlight: (a) Small, portable, electric light operated on one or more dry cells. (b) Trade name for an electric alarm clock.

flat-compound generator: Compound-wound generator having windings which give a constant voltage under different loads and speeds.

Fleming's rules: Rules for finding the direction of a conductor's motion through a magnetic field, the direction of the lines of force, and the direction of current flow through a conductor, applicable to direct current. Rule for Generators: Hold the thumb, the index finger, and the middle finger of the right hand so that they are at right angles to each other. The thumb will then point in the direction of the motion of the conductor, the index finger will point in the direction of the lines of force, and the middle finger will point in the direction of the current through the conductor. Rule for Motors: Hold the thumb, the index finger, and the middle finger of the left hand at right angles to each other. The thumb will then point in the direction of the motion of the conductor, the index finger will point in the direction of the lines of force, and the middle finger will point in the direction of current through the conductor.

flexible cable: Cable consisting of insulated, stranded or woven conductors.

flexible conduit: Non-rigid conduit made of fabric or metal strip wound spirally.

flexible cord: Insulated conductor consisting of stranded wire.

floating battery: Storage battery connected in parallel with a generator and the load, so that the battery will consume the surplus current from the generator if the load is small, and will supply additional current if the load exceeds the output of the generator.

flood lights: Battery of lamps of high brilliancy, equipped with reflectors to supply a strong light.

flow: Passage of a current through a conductor.

fluctuating current: Current which changes in voltage and amperage at irregular intervals.

flush receptacle. Type of lamp socket, the top of which is flush with the wall into which the socket is recessed.

flush switch: Push-button or key switch, the top of which is flush with the wall into which it is recessed.

flux: Magnetic lines of force existing between two opposite magnetic poles.

flux density: Number of lines of force in a given cross-sectional area, which is measured in gausses.

focus: The point where rays of light, heat, sound, etc., meet after being reflected or refracted.

foot candle: See "candle foot."

foot-pound: Unit for measuring work. It is the energy required to raise a weight of one pound through a distance of one foot.

force: Energy exerted between two or more bodies which tends to change their relative shape or position.

form factor: Ratio of effective value of one half of a cycle of an alternating current to the average value of similar half cycles.

formers: Forms used for producing a number of windings of the same shape.

form-wound coils: Coils or windings built up on formers before they are placed in their proper position on armatures, field poles, etc.

forming battery plates: Passing an electric current through a storage battery to deposit peroxide of lead and spongy lead on the plates which makes them active.

Foucault currents: Same as Eddy currents.

four-pole: (a) Having four poles, as in a generator. (b) Having four contacts, as in a four-pole switch.

four-way switch: Switch that controls the current in four conductors by making or breaking four separate contacts.

four-wire, three-phase system: Distribution system having a 3-phase star connection, one lead being taken from the end of each winding and the fourth from the point where they are all connected together.

fractional pitch: Term used when the number of slots between the sides of an armature coil is not equal to the number of slots of each pole.

franchise: Permit from municipal, state, or national government to use public property, such as streets, for special purposes, as the installation of street-car lines.

frequency: Number of cycles or vibrations per second.

frequency changer: Motor-generator driven by an alternating current of one frequency and delivering current of another frequency.

frequency convertor: Same as "frequency changer."

frequency indicator: Device showing when two alternating currents are in phase or have the same frequency.

frequency meter: Device showing the frequency of an alternating current.

friction tape: Tape coated with black adhesive compound, used as insulation on wire joints, etc.

frog: Fixture for street-car tracks or trolleys where one track or trolley branches off, permitting the car to be run from one track onto another.

full pitch: Term used when the number of slots between the sides of an armature coil is equal to the number of slots of each pole.

fuller cell: Primary electric cell having two electrolytes: sulphuric acid and water, and a bichromate solution. These are separated by a porous cup. A cone-shaped zinc electrode is immersed in the cup, which also contains the sulphuric-acid solution and an ounce of mercury, and a carbon electrode is immersed in the bichromate solution.

fundamental units: Basic standards of measurement.

fuse: Safety device to prevent overloading a current. It consists of a short length of conducting metal which melts at a certain heat and thereby breaks the circuit.

fuse block: Insulated block designed to hold fuses.

fuse clip: Spring holder for a cartridge-type fuse.

fuse cutout: Fuse which, when melted, cuts out the circuit.

fuse link: An open fuse, or a length of fuse wire for refilling fuses.

fuse plug: Fuse mounted in a screw plug, which is screwed in the fuse block like a lamp in a socket.

fuse strip: A length of ribbon fuse as distinguished from wire fuse.

fuse wire: Wire made of an alloy which melts at a comparatively low temperature.

G

G: (a) Abbreviation for gram. (b) Symbol for mho, the unit of conductivity.

gage: Device for measuring.

galvanized: (a) Affected by galvanic action. (b) Metal coated with zinc.

galvanometer: Device for measuring small currents and voltages.

gang switch: Two or more switches installed in one box or one holder.

gas-filled: Filled with a gas as, for instance, an ordinary electric lamp.

gasoline-electric: Pertaining to a machine consisting of a gasoline engine, a generator driven by the engine, and one or more motors to produce electric power.

gauge: Same as "gage."

Gauss: Unit of flux density equal to one maxwell per square centimeter.

gauze brush: Generator or motor brush made of copper gauze.

Geissler tube: Gas-filled tubes, with or without fluorescent liquids, solids, or both, which emit light of various colors when a high-frequency current is passed through them.

gelatine battery: Battery having a jelly-like electrolyte.

generator: Machine that produces electricity.

generator busbar: Conductors on power switchboards to which a generator is connected.

generator loss: Difference between power required to drive a generator and the power it delivers, which is always less than the power input.

generator output: Power delivered by a generator, measured in watts or kilowatts.

geographical equator: Imaginary line around the earth halfway between the poles.

german silver: Alloy containing copper, nickel, and zinc, which is used for making resistance wire.

gilbert: Unit for measuring magnetic force. One gilbert is the magnetic force which sends one maxwell of flux through a magnetic circuit having a reluctance of one oersted.

glaze: Smooth finish applied to porcelain insulators to close the pores in order to prevent the absorption of moisture.

gramme armature: A ring type of armature.

graphite: A form of soft carbon.

gravity cell: Primary electric cell having two electrolytes, copper sulphate, and sulphuric-acid solutions, which are separated by gravity. The electrodes are zinc and copper.

gravity drop: A shutter or plate of an annunciator which, when released from a catch, drops by gravity.

Greenfield conductor: Flexible cable having a spirally wound metal covering.

Grenet cell: Primary electric cell of which the electrolyte is a solution of bichromate of potash in a mixture of sulphuric acid and water, and the electrodes are zinc and carbon. The zinc electrode is lifted out of the electrolyte when the cell is not in use.

grid: (a) Frame of a storage-battery plate having spaces in which the paste is pressed. (b) An element of a vacuum tube which controls the rate of electron emission from the filament to the grid.

grid condenser: Small fixed condenser inserted in the line connecting with the grid of a vacuum tube used as a detector.

grid leak: Resistance shunted across a grid condenser in a radio circuit to allow dissipation of an excessive charge on the grid.

ground: See "earth."

ground circuit: Part of an electric circuit in which the ground serves as a path for the current.

ground clamp: Clamp on a pipe or other metal conductor connected to the ground for attaching a conductor of an electrical circuit.

ground detector: Device used in a power station to indicate whether part of the circuit is accidentally grounded.

ground indicator: Same as "ground detector."

ground plate: Metal plate buried in moist earth to make a good ground contact for an electrical circuit.

ground return: Ground used as one conductor of an electrical circuit.

ground wire: Conductor connecting an electrical device or circuit to the ground.

grounded neutral wire: The neutral wire of a 3-way distribution system which is connected to the ground.

grounded primary: Primary circuit of an induction coil or transformer connected to the ground.

grounding brush: Brush for making a ground connection to a moving part.

Grove cell: Primary electric cell which is similar to a Bunsen cell but has a platinum electrode instead of a carbon electrode.

growler: Coil around an iron core which is placed in contact with the core of an armature. When an alternating current or a pulsating direct current is passed through the growler coil, it magnetizes the core, which in turn induces a current in the armature winding. The purpose is to show whether a short circuit exists in the armature coil.

gutta percha: Hardened sap of a tropical tree which has high insulating quality and great resistance to destructive agencies such as water.

guy: A wire, rope, chain, or similar support for a structure such as a telephone pole, radio mast, etc.

H

H.: An abbreviation or symbol for intensity of magnetism.

h.p.: Horsepower.

hand advance: A device for controlling the advance and retard of the sparks in the ignition system.

hand regulation: Controlling the current or voltage by means of a hand operated device.

hard drawn copper: A method of producing high-grade copper of good mechanical strength.

hard fiber: A material made from a number of sheets of paper compressed tightly together. A good insulator.

hard rubber: An electrical insulation made by vulcanizing rubber.

harmonic currents: A series of currents which have frequencies that are multiple of the main current.

heat coil: A small coil placed on a telephone circuit to protect it from stray currents.

heat loss: The energy lost in a conductor due to its resistance.

heat run: A test made on a generator or motor to determine the amount of heating that takes place.

heating unit: That part of a heating appliance through which the current passes and produces heat.

head guy: A cable or wire fastened near the top of a pole to hold it in place.

head light: A light placed on the front end of a moving vehicle.

helix: A coil of wire; a solenoid.

henry: The electrical unit of inductance.

Hertzian wave: A radio wave.

high frequency: An alternating current that has many thousand cycles or alternations per second.

high potential: A high pressure or voltage, usually about six hundred volts.

high tension: A term used to refer to high voltage.

high tension magneto: A magneto used for ignition work in which the high-voltage current is produced in the magneto generator without the use of a separate induction coil.

holding magnet: An electromagnet used to hold metal objects while work is being done on them.

Holtz machine: A static electricity machine.

holophane: An electrical lighting globe with special surface for diffusing light.

homopolor generator: A generator having poles of one magnetic polarity only, instead of having alternate north and south pole.

hook-switch: A switch and hook on a telephone which is operated by placing or removing the receiver from that hook.

horizontal candle-power: The amount of light given off by a lamp measured in a horizontal direction from the light.

horn gap: A gap which is narrow at the bottom and widens out towards the top.

horsepower: The unit of power or work. An electrical horsepower is equal to 746 watts.

horsepower hour: The amount of power performed by 746 watts per one hour.

horseshoe magnet: A magnet bent in the shape of the letter U, or horseshoe.

hot conductor: A term used to refer to a conductor or wire which is carrying a current or voltage.

hot-wire meter: A meter which obtains a reading by the expansion of the length of wire or metal through which current flows.

howler: A device used in a telephone exchange to cause a noise in the receiver to indicate to the customer that the receiver has been left off the hook.

humming: A noise caused by the rapid magnetizing and demagnetizing of the iron core of a transformer, motor, or generator.

hunting: A condition in an electrical circuit where one machine tends to oscillate or run faster than another, and then run slower.

hydraulic: Pertaining to water or fluids in motion.

hydroelectric: The production of electricity by water-power.

hydrometer: An instrument or device which shows the specific gravity of a liquid as compared to water.

hysteresis: The tendency of magnetism to lag behind the current that produces it.

hysteresis curve: A curve that shows the relation between the magnetizing current and the amount of magnetism produced by it.

hysteresis loss: The heat produced by repeatedly magnetizing and demagnetizing the iron core of a machine.

I

I: An abbreviation for amperes of current.

I.E.S.: Illuminating Engineering Society.

i.h.p.: Indicated horsepower.

I-beam: A steel beam made in the form of a capital I.

idle coil: A coil which does not produce any voltage or through which no current flows.

ignition: The igniting of a combustible charge in the cylinder of a gas engine.

ignition battery: A battery used to furnish the ignition current for an automobile engine.

ignition coil: An induction coil that produces a high-voltage current which jumps the gap in a spark-plug and ignites the charge in an automobile engine.

ignition distributor: A device that connects the proper spark-plug to the high-tension current at the right time in an automobile engine.

ignition generator: A generator used to produce the ignition current for an automobile engine.

ignition spark: The spark that passes between the gaps of the spark-plug, inside an automobile cylinder.

ignition switch: A switch that is used for turning on and off the primary ignition coil.

ignition timer: A device that closes and opens the primary circuit of an induction coil at the proper instant, to produce a spark in a cylinder of an automobile engine.

illumination: The directing of light from its source to where it can be used to the best advantage.

impedance: The apparent resistance of a circuit to alternating current. It is composed of resistance and reactance.

impedance coil: A reactance or choke coil, used to limit the flow of current.

impregnated cloth: A cotton cloth that has been saturated with insulating varnish and dried.

impressed voltage: The voltage or pressure acting upon any device.

impulse: A sudden change, such as an increase or decrease in voltage or current.

incandescent lamp: A lamp in which light is produced by the heating of a small filament inside of a glass bulb.

inclined coil instrument: A voltmeter or ammeter in which the coil or moving vane are inclined in relation to the pointer.

incomplete circuit: An open circuit.

India rubber: A soft rubber used to insulate or cover electrical conductors and wires.

indicated horsepower: The horsepower determined by calculation taken from an indicator diagram.

indicating switch: A switch that shows whether it is turned "ON" or "OFF."

indirect lighting: Light that is thrown against a ceiling having a light colored surface and reflected and diffused in the room being lighted.

induced current: Current that is produced by inductance from another circuit.

induced e.m.f.: A voltage that is produced by induction from another circuit.

induced magnetism: Magnetism that is produced by electric current or by the action of other magnetism.

induced voltage: A voltage or pressure produced by induction.

inductance: The ability of an electric circuit to produce induction within itself.

inductance coil: A coil connected in an electric circuit in order to increase the resistance of that circuit to alternating current.

induction: The influence exerted by a magnet or magnetic field upon conductors.

induction coil: A coil used to produce a high-voltage. It consists of two windings placed on an iron core. The voltage is produced by stopping quickly the flow of current in the coil.

induction furnace: An electric furnace in which the metal forms a secondary circuit of the transformer and is heated by current flowing through the metal.

induction generator: An induction motor, operated about synchronous speed, which produces an electric current.

induction meter: A meter used on alternating current in which rotation of a disk is caused by the magnetic lines of force produced by a current and a voltage coil passing through the disk.

induction motor: An alternating-current motor which is operated by induced magnetism from the winding placed on the stator. It does not operate at synchronous speed.

induction regulator: A transformer in which the voltage produced in a secondary winding is varied by the changing of position of the primary winding.

inductive load: The load connected to an alternating-current system which causes the current to lag behind the voltage.

inductive reactance: The reactance produced by self-inductance.

inductive resistance: The apparent resistance that is caused by self-induction in a circuit.

inductor: That part of an armature winding which lies entirely on one side of the armature coil, and in which a voltage is produced.

industrial controller: A device or rheostat for controlling the speed of electric motors.

inertia: The tendency of a body to remain at rest or in motion at the same speed.

initial voltage: The pressure at the start; as the voltage at the terminal of a storage battery when it is placed on change; that voltage which causes the appearance of corona around an electric conductor.

input: All of the power delivered to an electric device or motor.

inside wiring: The wiring inside of a residence or building.

installation: All of the electrical equipment or apparatus used in a building including the wiring.

instrument transformer: A transformer used to change the voltage or current supplied to meters.

insulate: To place insulation around conductors or conducting parts of a device or object.

insulating: The placing of insulation around electrical conductors.

insulating compound: An insulating wax which is melted and poured around electrical conductors in order to insulate them from other objects.

insulating joint: A thread or coupling in which the two parts are insulated from each other.

insulation resistance: The resistance offered by an insulating material to the flow of electric current through it.

insulating varnish: A special prepared varnish which has good insulating property and is used to cover the coils and windings on electric machines and improve the insulation.

insulator: A device used to insulate electric conductors.

intake: A place where air or water enters a machine, tunnel, or pipe.

integrating meter: A meter that keeps the record of the total amount of power, current, etc., that passes through it in a given time.

intensity: The intensity of the current is the number of amperes that flows through a conductor in a given time.

intercommunicating telephone: A telephone system that connects up to the several offices in the same building or plant without the use of a central operator.

interior wiring: Wiring placed on the inside of buildings.

intermittent current: A current, that starts and stops its flow at regular intervals.

intermittent rating: When a machine is operated for a short time only and allows a long period of rest, it has an intermittent rating.

internal circuit: The circuit formed inside a device or machine.

internal resistance: The resistance of the winding of an electrical machine, or between terminals of a primary cell or a storage battery.

internal short-circuit: A short-circuit occurring between the positive and negative plates in a storage battery due to a defective separator.

internal wiring: The wiring inside of a device or a machine.

interpoles: Magnetic poles placed between the main poles of a motor or generator.

interrupter: A device that opens or closes a circuit many times per second.

interrupter contact: The contact where a circuit is broken by an interrupter.

interrupter gap: The greatest amount of distance or space between the contacts of an interrupter.

invar: A resistance wire composed of nickel and steel.

inverse ratio: A ratio where one value increases and the other value decreases.

inverted converter: A rotary or synchronous converter which changes direct current into alternating current.

ion: The two minute parts into which a molecule is divided when it is separated into its elements.

I^2R loss: The power loss due to the current flowing through the conductor which has resistance. This loss is converted into heat.

iron loss: The hysteresis and eddy current losses in iron cores of electric machinery.

ironclad armature: An armature in which the windings are placed in slots cut in the armature core.

ironclad magnet: A magnet which has an iron core extending around the outside of the coil and through which the magnetism flows.

isolated plant: An electric light plant used to furnish power for a small community or a few firms, and the power of the plant is not sold to the public.

J

J: Abbreviation for joule.

jack: The terminal of two telephone lines on a switchboard of a telephone exchange.

joint: The uniting of two conductors by means of solder.

joint resistance: The combined or total resistance of two or more resistances connected in series or parallel.

joule: A unit of electrical work. A current of one ampere flowing through a resistance of one ohm for one second.

journal: That part of a shaft that turns or revolves in the bearings.

jump spark: A spark that passes between two terminals or across a gap. It is produced by high voltage.

jumper: A temporary connection made around part of a circuit.

junction box: A box in a street distribution system where one main is connected to another main; also a box where a circuit is connected to a main.

K

K.: Abbreviation or symbol for dielectric constant.

k.w.: Abbreviation for kilowatt.

kaolin: A kind of clay used in making porcelain insulators.

keeper of magnet: A bar of soft-iron placed across the poles of a magnet when it is not being used.

Key: A device for opening and closing a circuit by moving a lever. It is used in telephone and telegraph apparatus.

key switch: A switch for turning on and off electric circuits which are operated by means of a special key.

key socket: A socket with a device that opens and closes the circuit, thus turning the lamp off or on.

keyless socket: A socket which does not have a key or device for turning on or off the lamp.

kicking coil: A reactance or choke coil.

kilo: A prefix when placed before a word means 1000 times that indicated by the word.

kiloampere: One thousand amperes.

kilovolt: One thousand volts.

kilowatt: One thousand watts.

kilowatt-hour: One thousand watt-hours.

knife switch: A switch that has a thin blade that makes contact between two flat surfaces or short blades to complete the circuit.

knob insulator: A porcelain knob to which electric wires may be fastened.

L

L.: An abbreviation for length.

lag: To drop behind.

lag of brushes: The distance the brushes are shifted on a motor or generator in order to prevent sparking.

lagging coil: A small coil used in alternating watt-hour meter to compensate for the lagging current in the voltage coil.

lagging current: The lagging of the current behind the voltage wave in an inductive alternating-current system.

laminated: Built up out of thin sheets or plates which are fastened together.

laminated core: A core built up of thin soft iron sheets placed side by side and fastened together.

laminations: One of the plates used in building a laminated core.

lamp: A device used to produce light.

lamp bank: A number of incandescent lamps connected in series or in parallel and used as resistances.

lamp base: The metal part of an incandescent lamp which makes contact with the socket.

lamp bulb: A term used in referring to an incandescent electric lamp.

lamp circuit: A branch circuit supplying current to lamps only, and not to motors.

lamp cord: Two flexible stranded insulated wires twisted together and used to carry the current from the outlet box to the lamp socket.

lamp dimmer: An adjustable resistance connected in a lamp circuit in order to reduce the voltage and the brightness of the lamps.

lamp socket: A receptacle into which the base of the lamp is inserted, and which makes connection from the lamp to the circuit.

lap winding: An armature winding in which the leads from the coil to the commutator lap over each other.

lap-wound armature: An armature that has a lap winding.

lateral: A conduit that branches off to the side from the main conduit.

lava: A kind of stone that has insulating properties.

lead (pronounced lĕd): An acid resisting metal that is used in making parts for storage batteries.

lead battery: A storage battery in which the plates are made from lead.

lead burning: The process of uniting two pieces of lead together by melting the edges.

leads (pronounced leeds): Short lengths of insulated wires that conduct current to and from a device.

lead of brushes: The distance that the brushes are moved on the commutator of a generator or motor to prevent sparking.

leading current: When the current of an alternating-current system reaches its maximum value before the voltage does, it is called a leading current.

leading-in wires: Wires used to carry current from the outside of buildings to the inside of buildings.

leak: A loss of charge in a storage battery where current can flow through a circuit, or to ground, due to defective insulation.

leakage flux: Lines of force or magnetism that do not flow through the path intended for them but take another path and do not do any useful work.

Leclanche cell: A primary cell which uses carbon and zinc rods or plates for electrodes.

left-hand rotation: A shaft or motor that revolves in a counter clockwise direction; that is, opposite to that of the hands of a clock.

Leyden jar: A glass jar covered inside and out with a thin metal covering, and used as a condenser.

lifting magnet: An electromagnet used to lift iron and steel objects.

light load: A load that is less than the usual or normal load on the circuit.

lighting fixture: An ornamental device that is fastened to the outlet box in the ceiling and which has sockets for holding the lamps.

lighting transformer: A transformer that is used to supply a distribution circuit that does not have motors connected to it.

lightning arrester: A device that allows the lightning to pass to the ground, thus protecting electrical machines.

lightning rod: A rod that is run from the ground up above the highest point of a building.

limit switch: A switch that opens the circuit when a device has reached the end of its travel.

line of force: An imaginary line which represents the direction of magnetism around a conductor or from the end of a magnet.

line drop: The loss in voltage in the conductors of a circuit due to their resistance.

line insulator: An insulator for use on an overhead transmission line.

line reactance: The reactance in the transmission line or conductor outside of the supply station.

line resistance: The resistance of the conductor forming the transmission line.

lineman: A man who erects or works on an electric transmission line.

link fuse: A fuse that is not protected by an outside covering.

litharge: A compound made from lead used in the active material of storage battery plates.

live: A circuit carrying a current or having a voltage on it.

load: The work required to be done by a machine. The current flowing through a circuit.

load control: Changing the output of a generator as the changes of load occur on a circuit.

load dispatcher: A person who supervises or controls the amount of load carried by the generating station on a system.

load factor: The average power consumed divided by the maximum power in a given time.

loading coils: Small coils placed in series with telephone lines in order to improve the transmission of speech.

local action: A discharge between different parts of a plate in a storage battery or primary cell caused by impurities in the parts used.

local current: An Eddy current.

locked torque: The twisting or turning power exerted by a motor when the rotating part is held stationary and normal current supplied to the winding.

lodestone: Magnetic iron ore.

log: A record of events taken down as they occur.

long shunt: Connecting the shunt across the series field and armature, instead of across the armature terminals.

loop circuit: A parallel or multiple circuit.

loop test: A test using the Wheatstone bridge, and a good line to locate an accidental ground on a line.

loose contact: A poor connection that does not make proper contact.

loud speaker: An electrical device that reproduces sound loud enough to be heard across a room.

low frequency: A current having a small number of cycles per second.

low potential: A system where the voltage between wires is usually less than 600 volts.

low tension: Low pressure or voltage.

low tension winding: The winding on a transformer which produces or has the lowest voltage.

low voltage release: A device that opens the circuit when the voltage drops down to a certain value, for which it is adjusted.

lugs: Terminals placed on the end of conductors to enable the wire to be attached or detached quickly.

lumen: The unit of electric lighting.

luminarre: An ornamental electric lighting fixture.

luminosity: In electric lighting work it is the brightness of a color compared with light.

luminous flux: In lighting work it is the amount of light directed down toward the point where it can be used.

M

M: A symbol of mutual induction the unit for which is a henry.

M.C.B.: Master Car Builder.

M.D.F.: Main distributing frame in a telephone exchange.

m.f.d.: Microfarad.

M-G: An abbreviation for motor-generator sets.

m.p.h.: Miles per hour.

machine rating: The amount of load or power a machine can deliver without overheating.

machine switching: A telephone exchange where the connections from one party to another are made by a machine instead of by an operator.

magnet: A body that will attract iron or steel.

magnet charger: A large electromagnet used to magnetize permanent magnets.

magnetic coil: The winding of an electromagnet.

magnet core: The iron in the center of the electromagnet.

magnet winding: The wire wound on a spool, forming an electromagnet.

magnet wire: A small single conductor copper wire insulated with enamel, cotton, or silk, used in winding armatures, field coils, induction coils, and electromagnets.

magnetic attraction: The pull or force exerted between two magnets or between magnets and an iron or steel body.

magnetic blow-out: A magnet arranged so that the arc between contacts is quickly lengthened and extinguished.

magnetic brake: A friction brake which is applied or operated by an electromagnet.

magnetic bridge: An instrument that measures the permeability and reluctance of magnetic material.

magnetic circuit: The paths taken by lines of force in going from one end of the magnet to the other.

magnetic compass: A small magnetized needle which indicates north and south directions.

magnetic contactor: A device, operated by an electromagnet, which opens and closes a circuit.

magnetic density: The amount of magnetism or magnetic lines of force per square inch or centimeter.

magnetic dip: The angles that a balanced needle makes with the earth when it is magnetized.

magnetic equator: An imaginary line joining the points about the earth where the compass needle does not have any dip.

magnetic field: The magnetic lines of force that pass in the space around a magnet.

magnetic flux: Magnetism or the number of lines of force in a magnetic circuit.

magnetic force: The attraction between magnetic poles or magnets, producing magnetism in a magnetic body by bringing it near a magnetic field.

magnetic lag: The tendency for magnetism to lag behind the current or force producing magnetism.

magnetic leakage: Lines of force that do not do useful work by passing through a path that is not in a working field.

magnetic lines of force: Magnetism about a conductor or flowing from magnet.

magnetic material: Materials which conduct lines of force easily—iron and steel.

magnetic needle: A small magnet that points in the direction of the magnetic lines of force about the earth.

magnetic pole: The ends of the magnet where the magnetism enters or leaves the magnet.

magnetic potential: Magnetic pressure which produces a flow of magnetic lines of force.

magnetic pulley: A pulley with an electromagnet inside of it, and used to separate iron and steel from other materials passed over it.

magnetic saturation: The greatest number of magnetic lines of force or magnetism that a body or substance can carry.

magnetic screen: A soft iron body around which magnetism is conducted instead of going through the center of that object.

magnetic shunt: A definite path for magnetic lines of force to pass through instead of the main path.

magnetic switch: A switch that is operated or controlled by an electromagnet.

magnetism: That invisible force that causes a magnet to attract iron and steel bodies.

magnetite: Magnetic iron ore.

magnetization curve: A curve that shows the amount of magnetism, expressed in lines of force, produced by a certain magnetizing force.

magnetize: To cause a substance to become a magnet.

magnetizing force: That force which produces magnetism. It is measured in ampere-turns.

magneto: A small generator that has a permanent field magnet.

magneto ignition: Igniting the charge in a combustion engine from a magneto generator.

magnetomotive force: That force which produces magnetism; it is expressed in ampere-turns.

main: The circuit from which all other smaller circuits are taken.

main feeder: A feeder supplying power from the generating station to the main.

make-and-break ignition: Igniting the charge in an internal combustion engine by the spark produced when contacts carrying current are opened.

maintenance: Repairing and keeping in working order.

manhole in conduit: An opening or chamber placed in a conduit run large enough to admit a man to splice or join cables together.

manganese steel: An alloy of steel having a large percent of the metal called manganese.

manual: Operated by hand.

mariner's compass: A compass used by sailors for directing the course of a ship.

master switch: A switch that controls the operation of other switches or contact switches.

maximum demand: The greatest load on a system occurring during a certain interval of time.

maximum demand meter: A meter that registers or indicates the greatest amount of current or power passing through a circuit within a given time.

maxwell: A unit of magnetic flux or lines of force.

mazda lamp: A certain trade name for an incandescent lamp using a tungsten filament.

mean horizontal candle-power: The average candle-power measured on a horizontal plane in all directions from the lamp filament.

mean spherical candle-power: The average candle-power of a lamp measured in all directions from the center of the lamp.

meg or mega: A prefix that means one million times.

megger: An instrument that measures the resistance in megohms.

megohms: A resistance of one million ohms.

mercury: A silvery white metal liquid; often called quicksilver.

mercury-arc rectifier: A rectifier in which alternating current is changed to direct current by the action of mercury vapor on electrodes.

mercury vapor lamps: The lamps or lights in which light is produced by passing a current through mercury vapor.

mesh connection: A closed circuit connection in armature winding.

messenger wire: A wire used to support a trolley, feeders, or cable.

metal conduit: Iron or steel pipe in which electric wires and cables are installed.

metal moulding: A metal tube or pipe, installed on the ceiling or walls of a building, in which electric wires are installed.

metallic circuit: A circuit that uses wires to return the current to the starting point instead of returning it through the ground.

metallic filament: An incandescent lamp filament made from a metal such as tantalum or tungsten.

meter: A device that records and indicates a certain value of electricity.

meter loops: Short pieces of insulated wire used to connect a watthour meter to the circuit.

metric system: A system of weights and measures based upon a meter (39.37 inches) for length and a gram ($\frac{1}{28}$ ounce) for weight.

Mho: The reciprocal of the resistance of a circuit which is called conductivity.

mica: A transparent mineral substance used for insulating commutators.

mica undercutter: A tool used to cut the mica below the surface of the commutator segment.

micanite: A trade name for small pieces of flake mica cemented together with an insulating compound.

micro: A prefix meaning one-millionth part.

micro-ampere: The one-millionth part of an ampere. $\frac{1}{1,000,000}$ or .000001 amperes.

microfarad: One-millionth of a farad.

microhm: One-millionth of an ohm.

microphone: A telephone transmitter in which the resistance is varied by a slight change in pressure on it.

microvolt: One-millionth of a volt.

mil: One-thousandth part of an inch; $\frac{1}{1000}$ or .001 inch.

mile-ohm: A conductor that is one mile long and has a resistance of one ohm.

mil-foot: A wire that is one-thousandth of an inch in diameter and one foot long.

milli: Prefix to a unit of measurement, denoting one-thousandth part of it.

milli-ammeter: An instrument that reads the current in thousandths of an ampere.

milli-ampere: $\frac{1}{1000}$ or .001 amperes. One-thousandth of an ampere.

milli-henry: One-thousandth of a henry.

milli-volt: One thousandth of a volt.

milli-voltmeter: A voltmeter that reads the pressure in one-thousandth of a volt.

mineralac: A trade name of an insulating compound or wax.

miniature lamp: The smallest size of incandescent lamp that uses a screw threaded base.

mirror galvanometer: A very sensitive galvanometer with a mirror attached to the moving element which reflects a spot of light over a scale.

moment: That which produces motion.

monel metal: An alloy of nickel and copper that is not eaten away by acids.

momentum: The tendency of a moving body to remain in motion at the same speed.

molecule: The smallest existing particle of a compound substance.

moonlight schedule: A list showing the time to turn the street lights out one hour after the moon rises, and turn them on one hour before the moon sets.

Morse code: A series of dots and dashes as signals transmitted by telegraph used to transmit messages.

motor: A machine that changes electrical energy into mechanical power.

motor converter: A form of rotary or cascade converter.

motor circuit: A circuit supplying current to an electric motor.

motor-generator: An electric motor driving a generator changing alternating to direct current or the reverse.

moulded insulation: A form of insulating material that can be placed in a mold and pressed into shape.

moulding: A wooden or metal strip provided with grooves to receive rubber covered electric wires.

moving coil meter: An electrical instrument of the d'Arsonval type which has a coil of fine wire moving between permanent magnets.

multiple: Connected in parallel with other circuits.

multiple circuit: A circuit in which the devices are connected in parallel with each other.

multiple series: A parallel connection of two or more series circuits.

multiple winding: A winding where there are several circuits in parallel.

multiple unit control: Controlling the operation of motors on several cars of an electric train from one point.

multiplex telegraphy: Sending one or more messages in both directions in the same circuit at the same time.

multiplex wave winding: A wave-wound armature that has more than two circuits in parallel.

multiplier: An accurately calibrated resistance connected in series with a voltmeter to enable it to be used on higher voltage circuits.

multipolar: Having more than two pole-pieces and field coils.

multi-speed: An electric motor that can be operated at several definite speeds.

mush coil: An armature coil that is not wound in regular layers.

N

N: A symbol used for revolutions per second or minute; often used to denote the North pole of a magnet.

N.E.C.: Abbreviation for National Electric Code; often called Underwriter's Code.

N.E.L.A.: Abbreviation for National Electric Light Association.

N.F.P.A.: Abbreviation for National Fire Prevention Association.

n.h.p.: Abbreviation for nominal horsepower.

name plate: A small plate placed on electrical machines which gives the rating of the machine and the manufacturer's name.

natural magnet: Magnetic ore or lodestone.

needle: A magnetized piece of steel which can be swung from the center and will point in the direction in which the magnetic lines of force are flowing.

needle point: The sharp point on a spark gap.

negative: The point towards which current flows in an external electrical circuit; opposite to positive.

negative brush: The brush of a generator out of which current enters the armature. In a motor the brush at which current leaves the armature.

negative charge: Having a charge of negative electricity.

negative conductor: The conductor that returns the current to the source after it has passed through a device and has been used.

negative electrode: The electrode by which the current leaves an electrolyte and returns to its source.

negative feeder: A feeder connected to the negative terminal on a generator to aid the current returning to the generator.

negative plate: The sponge lead plate of a lead acid-battery. In a primary cell the terminals to which the current returns from the external circuit.

negative pole: The S-pole of a magnet. The pole that the lines of force enter the magnet.

negative side: That part of the circuit from where the current leaves the consuming device to where it re-enters the generator.

negative terminal: That terminal to which the current returns from the external circuit.

neon: An inert gas used in electric lamps.

nernst lamp: A lamp in which light is produced by passing the current or electricity through rare oxide contained in a tube.

network: A number of electrical circuits or distribution lines joined together.

neutral: Not positive or negative although it may act as positive to one circuit and negative to another.

neutral conductor: A middle conductor of a three-wire direct-current or single-phase circuit.

neutral induction: The variation of current in one circuit which causes a voltage to be produced in another circuit.

neutral position: That point on the commutator where the armature conductors do not produce any voltage, because they are not cutting lines of force at that point.

neutral terminal: A terminal which may be positive to one circuit and negative to another circuit.

neutral wire: That wire in a three-wire distribution circuit which is positive to one circuit and negative to the other.

nichrome: An alloy of nickel and chromium which forms a resistance wire that can be used at a high temperature.

nickel: A silver white metal.

nickel silver: An alloy of copper, zinc, and nickel.

nickel steel: An alloy steel containing a small per cent of nickel.

nitrogen lamp: An incandescent lamp containing nitrogen or other inert gas instead of a vacuum.

non-conductor: That material which does not easily conduct electric current; an insulator.

non-inductive: Having very little self-induction.

non-inductive load: A load connected to a circuit that does not have self-induction. With alternating-current circuit, the current is in phase with the voltage.

non-inductive winding: A winding arranged so that it does not have any self-induction.

non-magnetic: Materials that are not attracted by a magnet are called non-magnetic.

normal: The general or usual conditions for that particular device or machine.

North pole: The end of the magnet at which the lines of force leave it. The end of a freely suspended magnet that will point towards the North.

numerator: In fractions the word or number written above the horizontal line.

O

O.K.: An abbreviation which means all right.

oersted: The unit of magnetic reluctance which is the resistance of metal to the flow of magnetism through them.

ohm: The unit used to express the resistance of a conductor to the flow of electric current through it.

Ohm's law: A rule that gives the relation between current, voltage, and resistance of an electric circuit. The voltage (**E**) is equal to the current (**I**) in amperes times resistance (**R**) in ohms. The current (**I**) equals the voltage (**E**) divided by the resistance (**R**) of the circuit. The resistance (**R**) is equal to the voltage (**E**) divided by the current (**I**).

ohm-mile: A conductor a mile long and has a resistance of one ohm.

ohmic resistance: The resistance of a conductor due to its size, length, and material.

oil circuit breaker: A device that opens an alternating-current circuit in a tank of oil which extinguishes the arc.

oil switch: A switch whose contacts are opened in a tank of oil.

oiled paper: A paper treated with an insulating oil or varnish.

open circuit: A break in a circuit. Not having a complete path or circuit.

open circuit battery: A primary cell that can only be used for a short time, and requires a period of rest in order to overcome polarization.

open coil armature: An armature winding in which the ends of each coil are connected to separate commutator bars.

open delta connection: A transformer connection in which two single-phase transformers are used to form two sides of a delta connection.

open wiring: Electric wires fastened to surfaces by the use of porcelain knobs. Wiring that is not concealed.

ordinate: The vertical lines drawn at various points along the horizontal base line to indicate values on that base line.

oscillating discharge: A number of discharges obtained one after another from a condenser; each one is less than the one before.

oscillograph: A very sensitive and rapid galvanometer which shows changes occurring in electrical circuits.

outboard bearing: A bearing placed on the outside of a pulley of a machine.

outlet: A place where electrical wires are exposed so that one can be joined to the other.

outlet box: An iron box placed at the end of conduit where electric wires are joined to one another and to the fixtures.

output: The amount of current in amperes or watts produced by a generator or a battery.

overcompound: When the series field coils of a generator are designed so that the voltage will increase with an increase in load, the generator is said to be overcompounded.

overdischarge: Discharge from a storage battery after the voltage has dropped to the lowest normal discharge value.

overhead: Electric light wires carried out doors on poles.

overload: Carrying a greater load than the machine or device is designed to carry.

overload capacity: The amount of load beyond a rated load that a machine will carry for a short time without dangerously overheating.

overvoltage: A voltage higher than the normal or usual voltage.

ozone: A form of oxygen produced by electrical discharge through air.

P

P: Abbreviation for power.

P.B.X.: Private branch telephone exchange.

P.D.: Potential difference.

panel box: The box in which switches and fuses for branch circuits are located.

parabolic reflector: A reflector built in the form of a parabolic curve in order to reflect the light in a narrow beam.

paraffin: A wax used for insulating bell wire.

parallax: The difference caused by reading the scale and pointer of an instrument at an angle instead of straight in front of it.

parallel: Two lines extending in the same direction which are equally distant at all points. Connecting machines or devices so that the current flows through each one separately from one line wire to another line wire. Also called multiple.

parallel circuit: A multiple circuit. A connection where the current divides and part flows through each device connected to it.

parallel series: A multiple series. A number of devices connected in series with each other, forming a group; and the groups are connected in parallel with each other.

parallel winding: A lap armature winding.

paramagnetic: Material that can be attracted by a magnet.

para rubber: The best grade of india rubber.

pasted plate: A storage battery plate in which the active material is prepared as a paste and forced into openings in the grid.

peak load: The highest load on a system, or generator, occurring during a particular period of time.

peak voltage: The highest voltage occurring in a circuit during a certain time.

pendant switch: A small push button switch, hanging from the ceiling by a drop cord, used to control the flow of current to a ceiling light.

permanent magnet: A magnet that holds its magnetism for a long time.

permeability: The ease with which a substance conducts or carries magnetic lines of force.

permeability curve: A curve that shows the relation of the magnetizing force (ampere-turns) and number of lines of force produced through a certain material.

permeameter: An instrument used to test the permeability of iron and steel.

permittivity: The dielectric constant.

peroxide of lead: A lead compound used in making storage battery plates.

petticoat insulator: An insulator the bottom part of which is in the shape of a cone with the inside hollow for some distance.

phantom line: An artificial line over which messages can be sent the same as over an ordinary line.

phase: The fraction of a period of cycle that has passed since an alternating voltage or current has passed through zero value in the positive direction.

phase advancer: A machine used to improve the power factor of a system by overcoming the logging current.

phase angle: The difference in time between two alternating-current waves expressed in degrees. A complete cycle of 360 degrees.

phase converter: A machine that changes the number of phases in an alternating-current circuit without changing the frequency.

phase failure: The blowing of a fuse or an opening of one wire or line in a two- or three-phase circuit.

phase indicator: A device that shows whether two electric machines are "in step" or in synchronism.

phase rotation: The order in which the voltage waves of a three-phase circuit reach their maximum value, as ABC or ACB.

phase shifters: Devices by which power-factor can be varied on a circuit when testing meters.

phase splitter: A device that causes an alternating current to be divided into a number of currents that differ in phase from the original.

phase winding: One of the individual armature windings on a polyphase motor or generator.

phosphor bronze: Bronze to which phosphor has been added in order to increase its strength.

photometer: An instrument used to measure the intensity of light.

pig tail: Five braided copper wires used to connect the carbon brush to its holder.

pike pole: A small pole with a sharp spike in one end. It is used by wiremen in raising and setting wood poles.

pilot brush: A small brush used to measure the voltage between adjacent commutator bars.

pilot cell: A cell in a storage battery used as a standard in taking voltage and specific gravity readings.

pilot lamp: A small lamp used on switchboards to indicate when a circuit switch or device has operated.

pitch: The number of slots between the sides of an armature coil. The distance from a certain point on one to a like point on the next.

pith balls: Small balls made from the light soft spongy substance in the center part of some plants and corn cobs.

pivots of meters: The shaft to which the moving part of the meter is fastened and which turns on a bearing.

Planté plates: A storage battery plate in which the active material is formed by charging and discharging the battery many times.

plate condenser: A condenser formed by a number of plates with insulating material between them.

plating dynamo: A generator that produces a low voltage direct current for use in electroplating work.

platinum: A gray-white metal that is not easily oxidized and which makes good contact points.

platinum-iridium: An alloy of platinum and iridium, which is a harder metal than platinum.

plug: A screw thread device that screws into an electric light socket and completes the connection from the socket to the wires fastened to the plug.

pocket meter: A small voltmeter or ammeter mounted in a case that can be carried in the coat pocket.

polar relay: A relay that operates when the direction of the flow of current changes.

polarity: Being positive or negative in voltage, current flow, or magnetism.

polarity indicator: An instrument that indicates the positive or negative wires of a circuit.

polarity wiring: Using a white or marked wire for the ground side of a branch circuit.

polarization: The forming of gas bubbles on the plates of a primary cell which reduces the current produced by the cell.

polarized: Having a definite magnetic polarity.

polarized armature: The armature of a magnet that has a polarity of its own and which is attracted only when the direction of the flow of current in the windings produces a pole of opposite polarity.

pole: The positive and negative terminal of an electric circuit. The ends of a magnet.

pole changer: A device that changes direct current into alternating current.

pole piece: The end of the field magnet or electromagnet that forms a magnetic pole.

pole pitch: The number of armature slots divided by the number of poles.

pole shoe: A piece of metal having the same curve as the armature that is fastened to the field magnet of a generator or motor.

pole strength: The number of magnetic lines of force produced by a magnet.

pole tips: The edges of the field magnets toward and away from which the armature rotates.

polyphase: Having more than one phase.

polyphase circuit: A two- or three-phase circuit.

polyphase transformer: A transformer in which the windings of all the phases are located inside the same case or cover.

porcelain: A hard insulating material made from sand and clay which is molded into shape and baked.

porous cell: A porous jar used with primary cells that use two different electrolytes that must be kept separate.

portable instrument: A meter so designed that it can be moved from one place to another.

positive: The point in a circuit from which the current flows; opposite to negative.

positive brush: The brush of a generator from which the current leaves the commutator; the brush of the motor through which current passes to the commutator.

positive electricity: The kind of electricity produced by rubbing a glass rod with silk.

positive electrode: The electrode or terminal that carries the current into the electrolyte.

positive feeder: A wire or cable acting as a feeder that is connected to the positive terminal of a generator.

positive plate: The peroxide of lead plate in a lead-acid storage battery.

positive terminal: The terminal of a battery or generator from which the current flows to the external circuit.

potential: The pressure, voltage, or electromotive force that forces the current through a circuit.

potential coil: The voltage or pressure coil of a meter that is connected across the circuit and is affected by changes in voltage.

potential regulator: A device for controlling or regulating the voltage of a generator or circuit.

potential transformer: A transformer used to step the voltage down for voltmeters and other instruments.

potentiometer: An instrument used to compare a known or standard voltage with another voltage.

pothead: A flared out pot or bell attached to the end of a lead covered cable and filled with insulating compound.

poundal: The unit of force which, acting for one second, will give a body that has mass of one pound a velocity of one foot per second.

power: The rate of doing work. In direct current circuits it is equal to **E** $\times$ **I**. The electrical unit is the watt.

power circuit: Wires that carry current to electric motors and other devices using electric current.

power factor: The ratio of the true power (watts) to the apparent power (volts $\times$ amperes). Cosine of the angle of lag between the alternating current and voltage waves.

power factor meter: A meter that indicates the power factor of the circuit to which it is connected.

power loss: The energy lost in a circuit due to the resistance of the conductors; often called I^2R loss.

power plant: The generators, machines, and buildings where electrical power or energy is produced.

practical units: The electrical units used in everyday practical work —the ohm, volt, ampere, watt, etc.

precision instrument or meter: A very accurate meter or instrument used in testing or comparing other meters.

press board: A hard smooth paper or cardboard used for insulation in generators and transformers.

pressure: The voltage which forces a current through a circuit; also called potential difference.

pressure wires: Wires going from the end of a feeder to a voltmeter in the power station.

primary: That which is attached to a source of power, as distinguished from the secondary.

primary cell: A cell producing electricity by chemical action, usually in acid acting on two different metallic plates.

primary circuit: The coil or circuit to which electric power is given and which transfers it to the secondary by induction.

primary winding: The winding which receives power from the outside circuit.

prime mover: An engine, turbine, or water wheel that drives or operates an electric generator.

prony brake: A friction brake or a pulley used as a dynamometer to measure the torque turning power of a shaft.

proportional: A change in one thing which causes a relative change in another thing.

protective reactor: A reactance coil used in a circuit to keep the current within a safe value when a short circuit occurs.

pull boxes: An iron box placed in a long conduit, or where a number of conduits make a sharp bend.

pull-offs: A hanger used to keep the trolley wire in proper place on a curve.

pulsating current: A current that flows in the same direction all the time, but rises and falls at regular intervals.

puncture: The breaking through insulation by a high voltage.

push button: A small contact device having a button which, when pressed, closes a circuit and causes a signal bell to ring.

push-button switch: A switch that opens and closes a circuit when a button is pushed.

push - pull transformer: A transformer used in radio work with a tap brought out at the center of the coil windings.

pyrometer: An instrument that indicates or measures temperatures higher than a thermometer will handle.

Q

Q: Abbreviation for "quantity" of electricity. The unit is coulomb or ampere-hours.

Q.S.T.: A radio code call—"Have you received the general call"?

quad: An abbreviation for quadruple telegraph; means Four.

quaded cable: A telephone or telegraph cable in which every two pairs (4 wires) are twisted together.

quadrature: Angle of 90 electrical degrees or quarter cycle difference between two alternating-current waves.

quarter phase: Same as two phase. The voltage waves are one-fourth of a cycle apart.

quick-break switch: A knife switch arranged so it will break the circuit quicker than when pulled open by hand.

R

R: Abbreviation for resistance, the unit of which is the ohm.

R.L.M.: Abbreviation for a dome type of lighting reflector.

r.p.m.: Abbreviation for revolutions per minute.

R.S.A : Railway Signal Association.

racing of motor: A rapid change or excessive speed of a motor.

raceways: Metal molding or conduit that has a thinner wall than standard rigid conduit used in exposed wiring.

racks and hooks: Supports for lead covered cables placed in underground manholes.

radial: In a straight line from the center outward.

radian: The angle at the center of a circle where the arc of circumstance is equal to the radius of the circle. It is 57.3 degrees.

radiation: The process of giving off or sending out light or heat waves.

radio: Referring to methods, materials, and equipment for communicating from one place to another without the use of wires between them.

radioactive: Giving off positive and negative charged particles.

rail bond: A short piece of wire or cable connecting the end of one rail to the next.

rating: The capacity or limit of load of an electrical machine expressed in horsepower, watts, volts, amperes, etc.

ratio: The relation of one number or value to another.

ratio arms: The two arms of a Wheatstone bridge whose resistances are known and form the ratio of the bridge.

ratio of a transformer: The relation of the number of turns in the primary winding to the secondary winding.

reactance: The influence or action of one turn of a coil or conductor upon another conductor which chokes or holds back an alternating current but allows a steady direct current to flow without any opposition.

reactance coil: A choke coil. It is used to hold back lightning and other high frequency currents in a circuit.

reactive current: That part of the current that does not do any useful work because it lags behind the voltage.

reactive load: A load, such as magnets, coils, or induction motors, where there is reactance which causes the current to lag behind the voltage.

reactor: Choke coils or condensers used in a circuit for protection or for changing the power factor.

reamer: A cone shaped tool used with a hand brace to remove the burr on the inner edge of conduit.

receiver: The part of the telephone that changes the talking current into sound that can be heard by the ear.

receiving sets: Devices used to receive radio messages and especially radio broadcast programs.

receptacle: A device placed in an outlet box to which the wires in the conduit are fastened, enabling quick electrical connection to be made by pushing an attachment plug into it.

receptacle plug: A device that enables quick electrical connection to be made between an appliance and a receptacle.

reciprocal: One divided by the number whose reciprocal is being obtained. The reciprocal of 2 is ½; of 3 is ⅓, etc.

recorder: A device that makes a record on paper of changing conditions in a circuit, apparatus, or equipment.

rectifier: A device that changes alternating current into continuous or direct current.

rectigon: Trade name for a battery charging rectifier.

red lead: Minimum, or peroxide of lead, used in making pasted battery plates.

re-entrant: Armature windings which return to a starting point, thus forming a closed circuit.

reflector: A device used to direct light to the proper place.

regenerative braking: Using electric motors on a car or locomotive as generators to slow down the train.

regulation: A change in one condition which causes a change in another condition or factor.

regulator: A device for controlling the current or voltage, or both, from a generator or through a circuit. Devices for controlling other machines.

relay: A device by which contacts in one circuit are operated by a change in conditions in the same or another circuit.

reluctance: The resistance to flow of magnetism through materials.

reluctivity: The reciprocal of permeability. The resistance to being magnetized.

remagnetizer: A large direct-current electromagnet used to magnetize the permanent magnets that have lost their magnetism.

remote control: Operating switches, motors, and devices located some distance from the control point by electrical circuits, relays, electromagnets, etc.

renewable fuse: An inclosed fuse so constructed that the fusing material can be replaced easily.

repeater: A device that reproduces the signals from one circuit to another.

repeating coil: An induction coil or transformer used in telephone work that has the same number of turns on each winding.

repulsion: The pushing of two magnets away from each other.

repulsion induction motor: An alternating current which operates as a repulsion motor during the starting period and as an induction motor at normal speed.

residual magnetism: The magnetism retained by the iron core of an electromagnet. Often the flow of current is stopped.

resistance: That property of a substance which causes it to oppose the flow of electricity through it.

resistance bridge: A Wheatstone bridge.

resistance furnace: A furnace where heat is obtained by electric current flowing through resistance coils.

resistor: Several resistances used for the operation control or protection of a circuit.

resonance: A condition in a circuit when the choke coil reactance is exactly balanced or equalized oy a condenser.

resultant: The sum of two forces acting on a body.

retarding coil: A choke coil.

retentivity: Holding or retaining magnetism.

retreiver: Device that pulls down the trolley pole of a car when the trolley wheel leaves the wire.

return circuit: The path the current takes in going from the apparatus back to the generator.

return feeders: Copper cables connected at different points of the rail to carry the current back to the generators.

reverse: Going in the opposite direction.

reverse current relay: A relay that operates when the current flows in the opposite direction to what it should.

reverse phase: A change in the phase of the current due to changing the generator or circuit wiring.

reverse power: Sending electric energy in the opposite direction in a circuit to the usual direction.

reversing switches: Switches used to change the direction of rotation of a motor.

rheostat: A resistance having means for adjusting its value.

ribbon conductor: A conductor made from a thin flat piece of metal.

right-hand rule: A rule used to determine the direction of flow of current in a dynamo.

ring armature: An armature with a core in the shape of a ring.

ring oiling: A system of oiling where a ring on the shaft carries oil to the top of the bearing.

ring system: Where two transmission lines from a station are joined together at a substation, thus forming a loop or ring.

risers: Wires or cables that are run vertically from one floor to another and supply electric current on these floors.

rocker arms: The arms to which the brush holders of a motor are fastened or supported.

rodding: Pushing short rods which are joined together through a conduit in order to pull a cable into it.

Roentgen rays: Similar to X-rays.

rosettes: A device to permit a drop cord to be attached to a ceiling outlet or fixture.

rotary converter: A direct-current motor with collector rings connected to the armature windings which changes alternating to direct current or the reverse; a synchronous converter.

rotary switch: A switch where the circuit is opened and closed by turning a knob or handle.

rotor: The part of an electrical machine that turns or rotates.

rotor slots: Openings punched in the disk of the rotor and in which the winding is placed.

r.p.m.: Abbreviation for revolutions per minute.

r.p.s.: Abbreviation for revolutions per second.

rubber-covered wire: Wires covered with an insulation of rubber.

rubber gloves: Insulated gloves worn by linemen when working on "Live" lines.

rubber tape: An adhesive elastic tape made from a rubber compound.

runner: The revolving part of a water turbine.

running torque: The turning power of a motor when it is running at rated speed.

runoff: The quantity of water flowing in a stream at any time.

S

s.: Abbreviation for second of time.

S.A.E.: Society of Automotive Engineers.

s.c.: Abbreviation for single contact.

s.c.c.: Abbreviation for single cotton-covered wire.

S.E.D.: Society for Electrical Development.

s.c.e.: Abbreviation for cotton enameled wire.

s.p.: Abbreviation for single pole.

S.S.: Abbreviation for steamship when placed before the name of the vessel.

s.s.c.: Abbreviation for single silk-covered wire.

S.K.F.: The trade name for a ball bearing.

safe carrying capacity: The maximum current a conductor will carry without overheating.

safety catch or fuse: A device that opens the circuit when it becomes too hot; often placed in base of appliances for heating liquids.

safety switch: A knife switch inclosed in a metal box and opened and closed by a handle on the outside.

salammoniac: Common name for ammonium chloride, NH_4Cl, used as electrolyte in primary cells.

salient poles: The ordinary poles formed at the end of a magnet as distinguished from consequent poles.

saturation curve: A curve showing the relation between the voltage produced by a generator and the ampere turns on the field coils.

Scott connection: A transformer connection for changing alternating current from two- to three-phase or the reverse.

seal: A piece of lead or metal used to close meter to prevent tempering.

second: $\frac{1}{60}$ part of a minute.

secondary: The circuit that receives power from another circuit, called the primary.

secondary battery: A storage battery.

secondary circuit: The wiring connected to the secondary terminals of a transformer, induction coil, etc.

secondary currents: Currents produced by induction due to changes in current values in another circuit.

section: An insulated length of line or circuit fed by a separate feeder.

sediment: Loose material that drops off storage battery plates and separators into bottom of cell.

segment: One of the parts into which an object is divided; often used to refer to commutator bars.

selector switch: A switch used in an automatic telephone system to locate an idle line.

selenium: A rare metal, the resistance of which changes when under action of light.

self-cooled transformer: A transformer in which the windings are cooled by contact with air or oil and without additional means for radiation.

self-discharge: The discharge of a cell due to leakage or short circuit inside of it.

self-excited: A generator in which the current in the field coils is produced by the generator itself.

self-induced current: An extra current produced in a circuit by change of the current flowing in that circuit.

self-inductance: The magnetic property of a circuit that tends to oppose a change of the current flowing through that circuit.

separators: Wood or rubber plates placed between the plates of a storage battery.

semaphore: A post or stand supporting a railroad signal.

separately-excited: A generator in which the current for the field coils is obtained from another generator or battery.

series: Connected one after another so the same current will flow through each one.

series arc lamp: An arc lamp in which the same current flows through all the lamps connected to the circuit.

series circuit: A circuit in which the same current flows through all the devices.

series generator: A constant-current generator used for operating a street lighting circuit where all lamps are connected in series.

series motor: A motor where all the current flows through the field coils and armature, because they are connected in series.

series-multiple: Same as series parallel.

series - parallel: An arrangement where several devices are connected into series groups and these groups are connected in parallel with each other.

series transformer: A current transformer. A transformer where the primary is connected in series with the circuit.

series winding: A wave-wound armature. A field coil winding through which the armature current flows.

service connections: The wiring from the distributing mains to a building.

service switch: The main switch which connects all the lamps or motors in a building to the service wires.

service entrance: The place where the service wires are run into a building.

service wires: The wires that connect the wiring in a building to the outside supply wires.

sheath: The outside covering which protects a wire or cable from injury.

shell transformer: A transformer with the iron core built around the coils.

shellac: A gum dissolved in alcohol, which forms a good insulating liquid.

sherardizing: Coating iron or steel with zinc to prevent rusting.

short: A contraction for short circuit.

short circuit: An accidental connection of low resistance joining two sides of a circuit, through which nearly all the current will flow.

short shunt: Connecting the shunt fields directly to the armature of a compound generator or motor instead of having them in parallel with armature and series fields.

short time rating: A device that can only operate for a short time without being allowed to cool.

shunt: A parallel circuit. A bypass circuit.

shunt coil: A coil connected in parallel with other devices and through which part of the current flows.

shunt field: A field winding connected in parallel with the armature.

shunt ratio: The ratio of current flowing through the shunt circuit to the total current.

shunt winding: A winding connected in parallel with the main winding.

shuttle armature: An H-type armature.

silicon bronze: A bronze or brass containing silicon and sodium which give it strength and toughness.

silicon steel: An alloy steel having low hysteresis and eddy current loss, used in transformer cores.

silk - covered wire: Small copper wires insulated by a covering of silk threads.

simplex circuit: A telegraph which sends in only one direction at a time.

simplex winding: A type of armature winding with two parallel paths from one brush to another.

sin: Abbreviation for sine of an angle; as sin 30°.

sine of an angle: In a right angle triangle it is the length of the side opposite the angle divided by the hypotenuse.

sine wave: The most perfect wave form. An alternating-current wave form.

single contact lamp: An automobile lamp which has one contact in end at base which makes contact with the socket; the side of the base and socket completes the circuit.

single phase: A generator or circuit in which only one alternating-current voltage is produced.

single-phase circuit: A 2- or 3-wire circuit carrying a single-phase current.

single-phase motor: An alternating-current motor designed to operate from a single-phase circuit.

single-pole switch: A switch that opens and closes only one side of a circuit.

single-stroke bell: A bell that strikes only once when the circuit is opened or closed.

single-throw switch: A knife switch that can be closed to one set of contacts only instead of two, as with a double-throw switch.

single-wire circuit: A circuit using one wire for one side and ground for the other side or return conductor.

single re-entrant: An armature winding in which the circuit is traced through every conductor before it closes upon itself.

sinusoid: A sine curve.

six phase: A circuit or machine where the voltage waves are $\frac{1}{6}$ of a cycle behind each other.

skin effect: The action of alternating current that causes more of a current to flow near the outside than in the center of a wire.

slate: A rock that is cut into slabs and used for switchboards. It is a fair insulator.

sleet cutter: A device placed on the trolley wheel to cut or scrape sleet from the trolley wire of a railway system.

sleeve joint: Joining the ends of two wires or cables together by forcing the ends into a hollow sleeve and soldering them.

sleeving: A small woven cotton tube slipped over the ends of armature leads to give additional insulation.

slide wire bridge: A Wheatstone bridge in which the balance is obtained by moving a contact over a wire.

slip: The difference in speed between the speed of a rotating magnetic field and the rotor of an induction motor.

slip ring: A ring placed on a rotor, which conducts the current from the rotor to the external circuit. Collector ring.

slot: The groove in the armature core where the armature coils are placed.

slot insulation: Material placed in armature slot to insulate the coils for the core.

slow-burning insulation: An insulation that chars or burns without a flame or blaze.

smooth core: An armature where the conductors are bound on the surface instead of being placed in slots or grooves.

snap switch: A rotary switch where the contacts are operated quickly by a knob winding up a spring.

sneak current: A weak current that enters a telephone circuit by accident. It will not blow a fuse, but it will do damage if allowed to continue.

soaking charge: A low rate charge given to a storage battery for a long time to remove excess sulphate from the plates.

soapstone: A soft oily stone sometimes used for insulating barriers. The powder is used when pulling wires into conduit.

socket: A receptacle or device into which a lamp bulb is placed.

sodium chloride: Common ordinary salt.

soft-drawn wire: Wire that has been annealed and made soft; often being drawn to size.

soldering flux: A compound that dissolves the oxide from the surfaces being soldered.

soldering paste: A soldering flux prepared in the form of a paste.

solenoid: A coil of insulating wire wound in the form of a spring or on a spool.

solenoid core: The soft iron plunger or body placed inside a solenoid.

solid wire: A conductor of one piece instead of being composed of a number of smaller wires.

sounder: A telegraph relay that delivers a sound at the receiving end which the operator can understand.

south pole: The end of a magnet at which the lines of force enter.

space factor: The actual cross-sectional area of copper in a winding divided by the total space occupied by the insulation and winding.

spaghetti insulation: A closely woven cotton tube impregnated with an elastic varnish that is slipped over ends of bare wires to insulate them.

spark coil: An induction coil used to produce a high voltage which causes a spark to jump a gap.

spark gap: A device which allows a high voltage current to jump a gap.

spark plug: A threaded metal shell having a center insulated conductor, which is screwed into the cylinder of an automobile engine.

spark voltage: The lowest voltage that will force a spark between two conductors insulated from each other.

sparking at brushes: Small arcs or flashes occurring between the commutator and brush, due to poor contact or incorrect brush position.

sparkless commutation: Operation of a direct-current generator or motor without any sparking at the brushes.

specific gravity: The weight of any volume of liquid or solid divided by the weight of an equal volume of water; or of any gas divided by an equal volume of air.

specific resistance: The resistance of a cube of any material which is one centimeter long on each edge.

speed counter: An instrument that records the number of revolutions made by a shaft.

speed regulation: The per cent of full load speed that the speed of a motor changes, when the load is suddenly removed.

sphere gap: A spark gap formed between two spheres fastened to conductors.

spherical candle-power: The average candle-power from a light measured in all directions.

spider: A cast-iron frame with radially projecting arms on which the rotating part of an electrical machine is built.

splice: The joining of the ends of two wires or cables together.

splice box: An iron box in which cable connections and splices are made.

split knobs: Porcelain knobs made into two pieces to receive a wire or cable and held together by a screw.

split phase: Obtaining currents of different phases from a single-phase circuit by use of reactances of different value in parallel circuits.

split-phase motor: A three-phase motor that is operated by split-phase current obtained from a single-phase circuit.

split-pole converter: A synchronous converter with divided or additional field poles for regulating the voltage.

sponge lead: Porous lead used in the active material of the negative plate of an acid storage battery.

spot welding: Uniting two metals together by electric welding them at several spots.

square mil: The actual area of a wire or conductor expressed in mils. The $\frac{1}{1,000,000}$ part of a square inch.

squirrel cage: The arrangement of copper rods in cylindrical form and fastened to copper rings at each end of the rotor core of an induction motor.

squirted filament: The old method of forcing a soft material for a lamp filament through small holes.

staggering of brushes: Arranging the brushes on a commutator so they will not all bear or rub on the same place.

stalling torque: The twisting or turning power of a motor, just before the armature stops turning, due to heavy load being applied.

standard candle: A standard of lighting power.

standard cell: A primary cell that gives the legal standard of voltage.

standard ohm: The unit of resistance.

standard resistance: An accurate resistance that is used for comparison with unknown resistances.

stand-by battery: A storage battery connected to the distribution system to carry the load should the generators fail.

static machines: Generators that produce static electricity.

star connection: Connecting one end of each phase of a three-phase circuit or machine together, thus forming a common point called the neutral. A Y-connection.

starter: A device that enables a safe current to be supplied to a motor when starting.

starting battery: A storage battery designed to deliver current to a motor used for starting an automobile engine.

starting box: A rheostat used for a short time when starting a motor.

starting current: The current taken by a motor when starting.

starting motor: A motor used for cranking an automobile engine.

starting rheostat: A starting box.

starting torque: The turning power produced by a motor when the rotor begins to turn on that power required to start a machine at rest.

static charge: A quantity of electricity existing on the plates of a condenser.

static electricity: Electricity at rest as distinguished from electric current, which is electricity in motion.

static generator: A machine producing static electricity.

static transformer: An ordinary transformer in which all parts are stationary as distinguished from the earlier constant-current transformer with a moving coil.

stator: The stationary part of an induction motor on which the field windings are placed.

steady current: A direct current whose voltage does not change or vary.

step-down: Reducing from a higher to a lower value.

step-up: Increasing, or changing from a low to a higher value.

stop charge device: A device that disconnects a storage battery from the charging circuit when it is completely charged.

storage battery: A number of storage cells connected together to give the desired current and voltage and placed in one case.

storage cell: Two metal plates or sets of plates immersed in an electrolyte in which electric current can be passed into the cell and changed again into chemical energy and then afterwards changed again into electrical energy.

strain insulator: An insulator placed in a guy wire to insulate it from the current-carrying wire.

stranded wires: Wires or cables composed of a number of smaller wires twisted or braided together.

stray current: Current induced in a conductor or core and which flows in these parts. The return current of an electric railway system that flows through adjacent pipes and wires instead of the regular return circuit.

stray field: Magnetic lines of force that do not pass through the regular path and therefore do not do any useful work.

stray flux: The lines of force of a stray magnetic field.

stray power: The power losses of an electrical machine due to heating effects, as friction, hysteresis, and eddy currents.

strength of current: The number of amperes flowing through the circuit.

strength of magnetism: The number of magnetic lines of force per unit of area.

strip fuse: A fuse made from a flat piece of metal.

Stubs' wire gauge: An iron wire gauge, often called Birmingham wire gauge.

sub-station: The building or place where one form of electrical energy is changed into another, as alternating current into direct current, high voltage to low, or the reverse.

sulphating: The forming of a hard white substance on the plates of a storage battery.

sulphuric acid: The kind of acid that is diluted and put in a lead storage battery.

superposed circuit: An additional circuit obtained from a circuit used for another purpose without interfering with the first circuit.

surface leakage: The leaking of current over the surface of an insulator from one metal terminal to another.

surges: An oscillating high voltage and current waves that travel over a transmission line after a disturbance.

surging discharge: A high voltage oscillating discharge.

susceptance: One of the components in an alternating circuit; the power component is called conductance and the wattless component is called susceptance.

susceptibility: The ratio of the amount of magnetism produced in a body to the magnetzing force.

suspension insulator: An insulator hung from a support and with the conductor fastened to the bottom of the insulator.

swinging cross: The blowing together of the wires of a transmission line, causing a short-circuit.

switch: A device for closing, opening, or changing the connections of a circuit.

switch blade: The movable part of a switch.

switchboard: The panel or supports upon which are placed the switches, rheostats, meters, etc., for the control of electrical machines and systems.

switchboard instruments: Meters mounted on a switchboard.

switch house or room: The part of the building in a power plant where the high voltage switches are located.

switch plate: A small plate placed on the plastered wall to cover a push button or tumbler switch.

switch tongue: The movable part of an electric railway track switch.

symbol: A letter, abbreviation, or sign that stands for a certain unit or thing.

synchronism: Alternating - current voltage waves that have the same frequency and reach their maximum value at the same instant.

synchronize: To bring to the same frequency and in phase.

synchronizer: A device for indicating when two machines are in synchronism.

synchronoscope: An instrument which shows when two machines are in synchronism and which machine is leading the other in phase.

synchronous condenser: A synchronous motor operated without load and strong field current in order to improve the power factor.

synchronous converter: A direct-current motor fitted with collector rings and used to change alternating to direct current.

synchronous motor: An alternating-current motor whose speed is in proportion to the frequency of the supply current and the number of poles in the machine.

synchronous phase advancer: A synchronous motor operated as a condenser to improve the power factor.

T

T: Abbreviation for temperature.

t: Abbreviation for time in seconds.

Ta: Chemical symbol for tantalum.

T-connector: A connector joining a wire to two branch circuits.

T-splice: A connection joining the end of one wire to the middle of another one.

tachometer: An instrument that shows the number of revolutions per minute made by a shaft.

talc: Powdered soapstone.

tan: An abbreviation for tangent of an angle.

tangent: A straight line that just touches the circumference of a circle.

tangent galvanometer: A galvanometer operated by current passing through a coil overcoming the earth's magnetism.

tap: A wire connected some distance from the end of the main wire or conductor.

tape: A narrow strip of treated cloth.

tapering charge: Charging a storage battery at constant voltage. The rate of current flow will decrease as the battery becomes charged.

taping: Wrapping layers of tape around a wire, coil, or conductor.

teaser winding: An extra winding on the poles of a series wound dynamo.

teeth of armature: The projections between the slots in an armature.

telegraph: A system of sending messages by dot and dash signals.

telegraph relay: A relay used in a telegraph circuit.

telegraph code: The dot and dash signals used for letters or words.

telephone: A device that transmits speech and sound from one place to another by electric currents.

telephone cable: A number of small insulated copper wires bound together and covered with paper, cotton, braid, or lead covering.

telephone condenser: A condenser used in a telephone circuit, made by rolling strips of tin foil between sheets of paraffin paper.

telephone cord: Several very flexible wires covered with a cotton braid. Used to connect one part to another.

telephone exchange: The place where all telephone lines end and connections are made from one line to another.

telephone jack: A receptacle into which a plug is placed when connecting one telephone line to another.

telephone receiver: A device that changes electric current in the telephone circuit into sound.

telephone repeating coil: A transformer used to reproduce the signals from one circuit to another.

telephone set: All the parts, such as transmitter, ringer, receiver, etc., installed for the subscriber's use on his premises.

temperature: Condition in regard to heat and cold.

temperature coefficient: The rate of change in resistance per degree change in temperature.

temperature correction: The amount that must be added to a reading taken at one temperature in order to make it comparable with the same reading taken at a standard temperature.

temperature rise: The difference in temperature between a certain part of a machine and the surrounding air.

tension: The degree of stretching; also sometimes used to refer to voltage, difference of potential, or dielectric stress.

terminal: A connecting device placed at the end of a wire, appliance, machine, etc., to enable a connection to be made to it.

terminal lug: A lug soldered to the end of a cable so it can be bolted to another terminal.

terminal pressure: The voltage at the generator or source of supply.

Tesla coil: An induction coil on a transformer without an iron core, used to produce high frequency currents.

test clip: A spring clip fastened to the end of a wire used to make connections quickly when testing circuits or devices.

test lamp: An incandescent lamp bulb and socket connected in a circuit temporarily when making tests.

test point: The metallic end of an insulated conductor used in making tests.

test set: Electrical instruments and devices used for testing, mounted for convenient use.

testing transformer: A transformer designed to deliver a number of different voltages, and used in testing for defects.

theater dimmers: Variable rheostats connected in series with a lighting circuit to control the voltage to the lamps and amount of light produced by them.

thermal: Pertaining to heat.

thermocouple: Two different metals welded together and used for the purpose of producing thermo-electricity.

thermo-electricity: Electricity produced by the heating of metals.

thermo-galvanometer: A galvanometer operated by the heating effect of a current acting on a thermocouple.

thermometers: Instruments for indicating relative temperatures.

thermostat: A device that opens and closes a circuit when the temperature changes.

third-brush generator: A small generator placed on an automobile to charge a storage battery.

third-brush regulation: A generator whose voltage is regulated by armature reaction and the shunt field current obtained from a third brush bearing on the commutator.

third rail: An insulated rail, placed along side of the rails on an electric railway, which supplies the power to the cars.

three-phase: A generator or circuit delivering three voltages that are $\frac{1}{3}$ of a cycle apart in reaching their maximum value.

three-phase circuit: A circuit delivering three-phase current.

three-phase motor: An alternating-current motor that is operated from three-phase circuit.

three-pole: A switch that opens and closes three conductors or circuits at one time.

three-way switches: A switch with three terminals by which a circuit can be completed through any one of two paths.

three-wire circuit: A circuit using a neutral wire in which the voltage between outside wires is twice that between neutral and each side.

three-wire generator: A direct-current generator with a balancer coil connected to the armature windings and the middle point of the balancer coil connected to the neutral.

tie wire: A short length of wire used to fasten the overhead wires to a pin insulator.

time switch: A switch controlled by a clock that opens and closes a circuit at the desired time.

timer: A device that opens the primary circuit of an induction coil at the right time to produce a spark to fire the charge in an internal combustion engine.

tinfoil: Sheets of tin rolled out thinner than paper.

tinned wire: Wire covered with a coating of tin or solder.

torque: The twisting or turning effort.

torsion dynamometer: An instrument that measures the torque of a machine by twisting a calibrated spring.

track circuit: The circuit through the rails and bonds.

track return: The return circuit formed by the rails and bonds of a track.

train lighting battery: A storage battery used to furnish electricity for lighting railroad cars.

transformer: A device used to change alternating current from one voltage to another. It consists of two electrical circuits joined together by a magnetic circuit formed in an iron core.

transformer coil: A part or one of the windings of a transformer.

transformer efficiency: The power delivered by a transformer divided by the power input to it.

transformer loss. The difference between the power input and output.

transformer oil: Oil used in a transformer to insulate the windings and carry away the heat.

transformer ratio: The ratio of the primary to the secondary voltages.

transformer substation: A substation where the alternating-current voltage is stepped up or down by use of transformers.

transite: A kind of asbestos lumber used for insulating barriers in dry places.

transmission line: High voltage conductors used to carry electrical power from one place to another.

transmitter: The telephone device that receives the speech and changes it into electric current.

transposition: Changing the relation of telephone and electric light wires to each other in order to equalize the inductance and prevent cross talk.

trickle charge: A low rate of charge given a storage battery.

triphase: Same as three-phase.

triple-pole switch: Same as a three-pole switch.

trolley wire: A wire supported over the tracks of an electric railway which carries the power for operating the cars.

true resistance: Actual resistance measured in ohms as compared to counter-electromotive force.

trunk: The wires or circuits between switchboards or telephone exchanges.

tube insulator: Insulating material made in the form of a tube and used to carry conductors through walls and partitions.

tumbler switch: A switch similar to a flush push button, but operated by pushing up or down on a short lever.

tungar rectifier: A rectifier using a tungar bulb made or licensed by the General Electric Company.

tungsten: A very hard metal with a high melting point that resists the effects of arcing.

tungsten filament: A filament made from tungsten and used in a lamp bulb.

tungsten steel: An alloy of steel and tungsten which produces a hard tempered steel which retains this property when heated a dull red.

twin cable: Two insulated wires running side by side without being twisted and covered with a braid.

twisted pair: Two rubber-covered telephone wires twisted together and used to connect subscriber's set to overhead wires or cable.

two-phase circuit: A circuit in which there are two voltages differing by one quarter of a cycle.

two-phase motor: A motor made to be operated from a two-phase circuit.

two-phase generator: A generator producing two-phase current.

two-pole: A switch that opens or closes both sides of a circuit or two circuits at one time.

two-wire circuit: A circuit using two wires.

U

ultra violet rays: Light rays that are beyond the violet color and not visible.

unbalanced load: A distribution system where there is a greater load on one phase or side than on the other.

undamped waves: Radio waves whose maximum rise and frequency is constant.

under-charged battery: A storage battery that has not been sufficiently charged.

under-compounded: A compound-wound generator in which the voltage drops as the load increases.

under-cut mica: Cutting the mica between commutator segments below the surface so it will clear the brush.

underground cable: A cable insulated to withstand water and electrolysis and placed in underground conduit.

underload circuit breaker: A conduit breaker that opens when the load drops below a certain value.

underload relay: A relay that operates another circuit when the load drops below a certain value.

Underwriters' Code: The National Electric Code.

unidirectional current: Current that flows in one direction.

uniphase: A single-phase alternating current.

unipolar: Having one pole.

unit price: Cost of one piece, foot, pound, or whatever number is taken as a unit for that particular material.

unloader: A device that removes the load from a machine, such as a compresser, when a motor is starting it.

V

V: Abbreviation for volts or potential difference.

V.T.: Abbreviation for vacuum tube or electron tube.

vacuum cleaner: A machine that sucks dust and dirt out of rugs, drapes, upholstery, etc.

vacuum impregnated: Filling the spaces between electric parts with an insulating compound while they are placed in a vacuum.

vacuum tube: Any kind of a bulb or tube from which the air has been removed.

vapor: A gas from a substance that is ordinarily a liquid or solid.

vapor rectifier: A mercury arc rectifier.

variable condenser: A condenser whose capacity can be varied.

variable resistance: A resistance that can be changed or adjusted to different values.

variable-speed generator: A generator operated at different speeds with a method of regulation which causes it to deliver a constant voltage.

variable-speed motor: A motor whose speed depends upon the load.

Varley loop: A method of locating a cross, short-circuit, or ground on telephone or telegraph lines.

varnished cambric or cloth: Cotton cloth treated with an insulating varnish.

vector: A line whose length and direction represents a certain physical quantity.

vector diagram: A diagram that shows relations by use of vectors.

verdigris: A substance called copper sulphate that forms on copper by the action of sulphuric acid.

vibrating rectifier: A device that changes alternating current into direct current by means of a vibrating contact that closes the circuit for one-half of the cycle and opens it when the flow of alternating current is in the opposite direction.

vibrator coil: An induction coil used as an ignition coil.

volt: A unit of electrical pressure or electromotive force.

voltage coil: A coil connected across the line so that the current flowing through it changes as the voltage changes.

voltage drop: The difference in pressure between two points in a circuit caused by the resistance opposing the flow of current.

voltage loss: The voltage drop.

voltage regulator: A device for keeping a constant voltage at a certain point.

voltaic battery: A number of primary cells connected in series or parallel.

voltammeter: A voltmeter and ammeter combined in one case and using the same movement, but having separate terminals.

volt-ampere: The unit of apparent power; it is the product of the pressure times the current.

voltmeter: An instrument that shows the pressure or voltage of a circuit

vulcabeston: An asbestos and rubber composition used to make moulded parts.

vulcanite: A kind of hard rubber.

vulcanized fiber: An insulating material made of paper and cellulose under heavy pressure.

W

W: Abbreviation for watt.

W.A.E.I.: Western Association of Electrical Inspectors.

wall box: A metal box for switches, fuses, etc., placed in the wall.

wall insulator: An insulating tube used to protect a conductor passing through a wall.

wall socket: An electric outlet placed in the wall so that conductors can be connected to it by means of a plug.

water-cooled transformer: A large transformer having coiled pipes inside it through which water passes.

water rheostat: A rheostat that has its terminals placed in water through which the current flows.

watt: The unit of electric power.

watt-hour: The use of a watt of power for an hour.

watt-hour meter: An instrument that records the power used in watt-hours.

watt meter: An instrument used to indicate the power being used in a circuit.

watt minute: A power of one watt being used for one minute. $\frac{1}{60}$ of a watt-hour.

wattless: Not having any power or doing any useful work.

wave meter: An instrument used to determine the wave length or frequency of a radio broadcasting station.

wave winding: An armature winding with the end of the coils connected to commutator bars that are nearly opposite each other in a 4-pole machine.

weatherproof: Constructed so it will resist the action of rain, sun, etc.

welding transformer: A transformer built to deliver a large current used to heat metals to a welding temperature.

welding flux: A material, usually borax, used to remove scale from the joints being welded.

Western Union splice: A method of uniting two wires together by wrapping each one about the other.

Weston cell: A primary cell that has a constant voltage and used as a standard source of electrical pressure.

wet storage: A method of keeping a storage battery when it is not being used without removing the acid or plates.

Wheatstone bridge: An electrical balance used to measure resistance by comparing a known resistance with an unknown.

windage: The resistance of air against the rotating part of a machine.

wiping contact: A contact that rubs between two other contacts.

wire: A slender rod of drawn metal.

wire gauge: A method of expressing the diameter of different wires.

wired radio: Transmitting radio messages along telephone, electric light, and power lines instead of directly through the air.

wiring connector: A device for joining wire to another.

wiring symbols: Small signs placed on a wiring diagram to indicate different devices and connections.

wood separator: A thin sheet of wood placed between the plates of a storage.

wrought iron: A kind of iron that can be easily magnetized.

X

x: A symbol used to represent an unknown quantity.

x: A symbol for reactance, expressed in ohms.

X-ray: A kind of ray that passes through most materials as if they were transparent.

Y

Y: A symbol for admittance; the unit of which is mho.

Y-connection: A star connection; the joining together of one end of each phase of a 3-phase machine.

yoke: The iron frame of a generator or motor to which the magnetic pole pieces are fastened.

Z

Z: Symbol for impedance.

zero potential: Not having any voltage or pressure.

zinc battery: A primary cell in which the electric current is produced by zinc plates immersed in an electrolyte.

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

(Based on Room Temperature of 30°C. or 86°F.)

TABLE 1. Not More than Three Conductors in Raceway or Cable

Size AWG MCM	Rubber Type R Type RW Type RU (14-2) / Thermo-plastic Type T (14-4/0) Type TW (14-4/0)	Rubber Type RH	Paper: Thermo-plastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impreg-nated Asbestos Type AI (14-8) Type AIA	Asbestos Type A (14-8) Type AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	270	315	335	...
300	240	285	300	345	380	...
350	260	310	325	390	420	...
400	280	335	360	420	450	...
500	320	380	405	470	500	...
600	355	420	455	525	545	...
700	385	460	490	560	600	...
750	400	475	500	580	620	...
800	410	490	515	600	640	...
900	435	520	555	...	...	...
1,000	455	545	585	680	730	...
1,250	495	590	645	...	...	...
1,500	520	625	700	785	...	...
1,750	545	650	735	...	...	...
2,000	560	665	775	840	...	...

TABLE 2. Single Conductor in Free Air

Size AWG MCM	Rubber Type R Type RW Type RU (14-2) / Thermo-plastic Type T Type TW	Rub-ber Type RH	Thermo-plastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	As-bestos Var-Cam Type AVA Type AVL	Impreg-nated As-bestos Type AI (14-8) Type AIA	As-bestos Type A (14-8) Type AA	Slow-Burning Type SB / Weather-proof Type WP Type SBW
14	20	20	30	40	40	45	30
12	25	25	40	50	50	55	40
10	40	40	55	65	70	75	55
8	55	65	70	85	90	100	70
6	80	95	100	120	125	135	100
4	105	125	135	160	170	180	130
3	120	145	155	180	195	210	150
2	140	170	180	210	225	240	175
1	165	195	210	245	265	280	205
0	195	230	245	285	305	325	235
00	225	265	285	330	355	370	275
000	260	310	330	385	410	430	320
0000	300	360	385	445	475	510	370
250	340	405	425	495	530		410
300	375	445	480	555	590		460
350	420	505	530	610	655		510
400	455	545	575	665	710	...	555
500	515	620	660	765	815	...	630
600	575	690	740	855	910	...	710
700	630	755	815	940	1005	...	780
750	655	785	845	980	1045	...	810
800	680	815	880	1020	1085	...	845
900	730	870	940	....	....	....	905
1000	780	935	1000	1165	1240	....	965
1250	890	1065	1130	....	....	....	....
1500	980	1175	1260	1450	....	....	1215
1750	1070	1280	1370	....	....	....	....
2000	1155	1385	1470	1715	....	....	1405

Courtesy of National Board of Fire Underwriters

NATIONAL ELECTRICAL CODE STANDARDS

CARRYING CAPACITY OF WIRES

The carrying capacity of wires used in electric wiring work depends upon the ability of the insulation, wire, and covering on the wire to radiate the heat (which is produced by the current flowing through the wire) without injuring the insulation on the wire. The ability to radiate heat depends upon (1) circulation of air around the wires; (2) the number of current-carrying wires inside the conductor covering; and (3) the temperature of the room. The higher the room temperature, the less the heat that can be radiated by the insulation before the temperature of the insulation exceeds the safe maximum. The neutral of a three-wire circuit is not counted as a current-carrying conductor, because it carries only the unbalanced load. However, the neutral used with the two-phase wires of a Y-connected system is a current-carrying conductor.

Conduit Wiring. The maximum allowable current-carrying capacity for the different sizes of conductors or wires, expressed in amperes and based upon a room temperature of 86°F., is given in Table 1. This table assumes that there are not more than three current-carrying conductors inside the raceway or covering of the cable. When four to six conductors are run in a raceway or cable, the allowable current-carrying capacity of each conductor shall be reduced to 80% of the values in Table 1. If seven to nine conductors are run in a raceway or cable, the allowable current-carrying capacity of each conductor shall be reduced to 70% of the values in Table 1.

Knob and Tube Wiring. Table 2 gives the allowable current-carrying capacity of conductors when installed as single conductors in free air. This type of construction is used with open conductors on insulators, concealed knob and tube wiring, switchboards and controller wiring, and work of similar type.

TYPES OF INSULATION

Table 3 gives facts regarding the different types of insulation, the Underwriters' type letter designation for each particular type of wire, and also the general trade name by which it is known. The type letter is an abbreviation of the material used in the insulation. Thus *R* is used for *rubber insulation.* This is the type of rubber-covered wire

TABLE 3. Conductor Insulations

For Wiring Circuits under 600 Volts

Trade Name	Type Letter	Insulation	Outer Covering	Use
Code	R	Code Grade Rubber	Moisture-Resistant Flame-Retardant Fibrous Covering	General Use
Moisture-Resistant	RW	Moisture-Resistant Rubber	Moisture-Resistant Flame-Retardant Fibrous Covering	General Use, Especially in Wet Locations
Heat-Resistant	RH	Heat-Resistant Rubber	Moisture-Resistant Flame-Retardant Fibrous Covering	General Use
Latex Rubber	RU	90 Per Cent Unmilled Grainless Rubber	Moisture-Resistant Flame-Retardant Fibrous Covering	General Use
Thermoplastic	T and TW	Flame-Retardant Thermoplastic Compound	None	T—General Use; TW—in Wet Locations
Thermoplastic and Asbestos	TA	Thermoplastic and Asbestos	Flame-Retardant Cotton Braid	Switchboard Wiring Only
Asbestos and Varnished Cambric	AVA	Impregnated Asbestos and Varnished Cambric	Asbestos Braid	Dry Locations Only
Asbestos and Varnished Cambric	AVB	Same as Type AVA	Flame-Retardant Cotton Braid	Dry Locations Only
Asbestos and Varnished Cambric	AVL	Same as Type AVA	Asbestos Braid and Lead Sheath	Wet Locations
Slow Burning	SB	3 Braids Impregnated Fire-Retardant Cotton Thread	Outer Cover Finished Smooth and Hard	Dry Locations Only
Slow Burning Weatherproof	SBW	2 Layers Impregnated Cotton Thread	Outer Fire-Retardant Coating	Open Wiring Only

that has been used in the past for interior wiring and is now known as *Code-Grade type R* because it meets the National Board of Fire Underwriters' Code requirements for wiring. Type *R* wire is the lowest priced wire, and the one most commonly used in wiring work. Where the maximum operating temperature may exceed 122°F., it is necessary to use a higher quality of rubber insulation; this is known as the heat-resistant grade, type *RH* wire. The two types, *R* and *RH*, are the only ones permitted for concealed knob and tube wiring.

Type *RW*, which is known as the moisture-resistant rubber insulation, is intended for general use, especially in "wet locations." A wet location is one that is subject to saturation with water or with other liquids; for example, locations exposed to the weather, washrooms in garages, etc. Installations that are underground, or in concrete slabs, or masonry in direct contact with the earth, are also considered as wet locations. Moisture-resistant rubber insulation is used where condensation and accumulation of moisture within the raceway is likely to occur.

The types *T* and *TW* do not have rubber insulation. Instead, a flame-retardant thermoplastic compound is used. It is used for rewiring existing raceways, usually in sizes 14, 12, and 10; and up to 2,000 MCM.

The varnished cambric insulation is denoted by the letter *V* and is generally intended for dry locations. There is no rubber used in insulating the conductors; the insulation is composed of layers of a closely woven cloth called cambric, to which an insulating varnish has been applied. These layers of cambric are usually wound in opposite directions spirally around the conductors. When the cable is covered with a lead sheath, as is the type *AVL*, it can be used in wet locations.

Wire covered with insulation of the slow-burning type, *SB*, and the slow-burning weatherproof, *SBW*, can only be used in dry locations and within certain limits of room temperature. They are not used to a large extent in interior electric wiring work.

MAXIMUM WIRES IN CONDUIT

Table 4 gives sizes of rigid conduit and thin wall tubing and maximum number of rubber-covered wires that can be installed. It applies

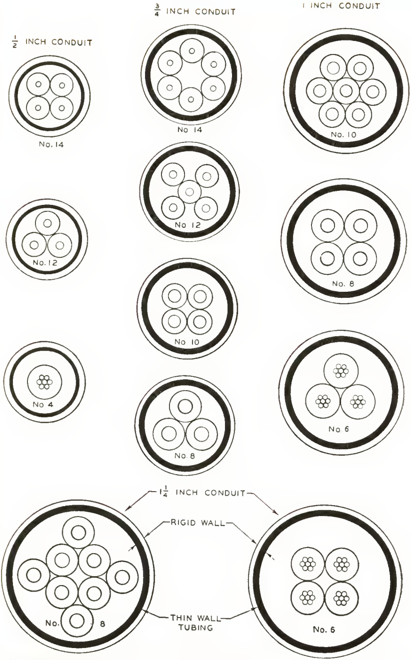
TABLE 4. Number of Conductors in Conduit or Tubing

Rubber-Covered Types RF-32, R, RH, RW, and RU; Thermoplastic Types TF, T, and TW—One to Nine Conductors

Size AWG MCM	Number of Conductors in One Conduit or Tubing								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	*1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1½	1½	2	2½	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	4½
300	1¼	2½	2½	3	3½	4	4	4½	4½
350	1¼	3	3	3½	3½	4	4½	4½	5
400	1½	3	3	3½	4	4	4½	5	5
500	1½	3	3	3½	4	4½	5	5	6
600	2	3½	3½	4	4½	5	6	6	6
700	2	3½	3½	4½	5	5	6	6	...
750	2	3½	3½	4½	5	6	6	6	...
800	2	3½	4	4½	5	6	6	...	...
900	2	4	4	5	6	6	6	...	...
1000	2	4	4	5	6	6	...	...	...
1250	2½	4½	4½	6	6	...	...	...	...
1500	3	5	5	6	...	...	...	...	...
1750	3	5	6	6	...	...	...	...	...
2000	3	6	6	...	...	...	...	...	...

*Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end, two No. 4 insulated and one No. 4 bare conductors may be installed in 1-inch conduit or tubing. *Courtesy of National Board of Fire Underwriters.*

to a complete conduit system. When the distance does not exceed 50 feet, and for services, the number of wires may be increased as explained in the footnote. This table does not apply to short sections of conduit used for the protection of exposed wiring from mechanical injury.



ACTUAL SIZE OF METALLIC TUBING (SOLID CIRCLE) AND RIGID CONDUIT (OUTER CIRCLE) SHOWING THE MAXIMUM NUMBER OF WIRES (TYPE R INSULATION)

Electrical Formulas

OHM'S LAW

Ohm's Law is a method of explaining the relation existing between voltage, current, and resistance in an electrical circuit. It is practically the basis of all electrical calculations. The term "electromotive force" is often used to designate pressure in volts. This formula can be expressed in various forms.

To find the current in amperes:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \quad \text{or} \quad \text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \text{or} \quad I = \frac{E}{R}$$

The flow of current in amperes through any circuit is equal to the voltage or electromotive force divided by the resistance of that circuit.

To find the pressure or voltage:

$$\text{Voltage} = \text{Current} \times \text{Resistance} \quad \text{or} \quad \text{Volts} = \text{Amperes} \times \text{Ohms}$$
$$\text{or} \quad E = I \times R$$

The voltage required to force a current through a circuit is equal to the resistance of the circuit multiplied by the current.

To find the resistance:

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \quad \text{or} \quad \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}} \quad \text{or} \quad R = \frac{E}{I}$$

The resistance of a circuit is equal to the voltage divided by the current flowing through that circuit.

POWER FORMULAS

One horsepower = 746 watts One kilowatt = 1000 watts

DIRECT-CURRENT CIRCUITS

$$\text{Power in Watts} = \text{Volts} \times \text{Amperes}$$

To find current in amperes:

$$\text{Current} = \frac{\text{Watts}}{\text{Voltage}} \quad \text{or} \quad \text{Amperes} = \frac{\text{Watts}}{\text{Volts}} \quad \text{or} \quad I = \frac{W}{E}$$

$$\begin{array}{c}\text{Current} \\ \text{(of a motor)}\end{array} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Efficiency}} \quad \text{or} \quad I = \frac{\text{hp.} \times 746}{E \times \text{Eff.}}$$

To find the pressure or voltage:

$$\text{Voltage} = \frac{\text{Watts}}{\text{Current}} \quad \text{or} \quad \text{Volts} = \frac{\text{Watts}}{\text{Amperes}} \quad \text{or} \quad E = \frac{W}{I}$$

SINGLE-PHASE ALTERNATING-CURRENT CIRCUITS

Power in Watts = Volts × Amperes × Power Factor

To find current in amperes:

$$\text{Current} = \frac{\text{Watts}}{\text{Voltage} \times \text{Power Factor}} \quad \text{or}$$

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts} \times \text{Power Factor}} \quad \text{or} \quad \mathbf{I} = \frac{\mathbf{W}}{\text{E} \times \text{P.F.}}$$

$$\begin{array}{c}\text{Current}\\ \text{(of a motor)}\end{array} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Power Factor} \times \text{Efficiency}} \quad \text{or}$$

$$\mathbf{I} = \frac{\text{hp.} \times 746}{\text{E} \times \text{P.F.} \times \text{Eff.}}$$

TWO-PHASE ALTERNATING-CURRENT CIRCUITS

Power in Watts = Volts × Amperes × Power Factor × 2

To find current in amperes in each wire:

$$\text{Current} = \frac{\text{Watts}}{\text{Voltage} \times \text{Power Factor} \times 2} \quad \text{or}$$

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts} \times \text{Power Factor} \times 2} \quad \text{or} \quad \mathbf{I} = \frac{\mathbf{W}}{\text{E} \times \text{P.F.} \times 2}$$

$$\begin{array}{c}\text{Current}\\ \text{(of a motor)}\end{array} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Power Factor} \times \text{Efficiency} \times 2}$$

THREE-PHASE ALTERNATING-CURRENT CIRCUITS

Power in Watts = Volts × Amperes × Power Factor × 1.73

To find current in amperes in each wire:

$$\text{Current} = \frac{\text{Watts}}{\text{Voltage} \times \text{Power Factor} \times 1.73} \quad \text{or}$$

$$\text{Amperes} = \frac{\text{Watts}}{\text{Volts} \times \text{Power Factor} \times 1.73} \quad \text{or} \quad \mathbf{I} = \frac{\mathbf{W}}{\text{E} \times \text{P.F.} \times 1.73}$$

$$\begin{array}{c}\text{Current}\\ \text{(of a motor)}\end{array} = \frac{\text{Horsepower} \times 746}{\text{Volts} \times \text{Power Factor} \times \text{Efficiency} \times 1.73}$$

The power factor of electric motors varies from 80% to 90% in the larger size motors. The efficiency likewise varies from 80% on a small motor to 90% on a large motor.

CALCULATING SIZE OF CONDUCTOR

SINGLE-PHASE, TWO-PHASE, AND DIRECT-CURRENT CIRCUITS

To find size of conductor required:

$$\text{Circular Mils} = \frac{21.6 \times \text{Current in Amperes} \times \text{Distance in Feet}}{\text{Volts Drop}}$$

To find the voltage drop in a circuit:

$$\text{Volts Drop} = \frac{21.6 \times \text{Current in Amperes} \times \text{Distance in Feet}}{\text{Circular Mils}}$$

To find current flowing:

$$\text{Current} = \frac{\text{Circular Mils} \times \text{Voltage Drop}}{21.6 \times \text{Distance in Feet}}$$

To find allowable length of circuit for given voltage drop or loss:

$$\text{Length of Circuit} = \frac{\text{Circular Mils} \times \text{Voltage Drop}}{21.6 \times \text{Current in Amperes}}$$

THREE-PHASE ALTERNATING-CURRENT CIRCUITS

To find size of conductor required for a three-phase circuit:

$$\text{Circular Mils} = \frac{10.8 \times \text{Current in Amperes} \times \text{Distance in Feet} \times 1.73}{\text{Volts Drop}}$$

To find voltage drop in a three-phase circuit:

$$\text{Volts Drop} = \frac{10.8 \times \text{Current in Amperes} \times \text{Distance in Feet} \times 1.73}{\text{Circular Mils}}$$

To find current in a three-phase circuit:

$$\begin{array}{c}\text{Current}\\ \text{(Amperes)}\end{array} = \frac{\text{Circular Mils} \times \text{Voltage Drop}}{10.8 \times \text{Distance in Feet} \times 1.73}$$

To find length of a three-phase circuit for a given voltage drop:

$$\text{Distance in Feet} = \frac{\text{Circular Mils} \times \text{Voltage Drop}}{10.8 \times \text{Current in Amperes} \times 1.73}$$

HANDY TABLES

In the following tables the values of different units are given so that you may be able to express the value of one unit in an equivalent term of another unit. As 1 foot = 12 inches = 0.333 yards, etc. In order to change the values from one set of units to another, all that is required is to multiply by the equivalent or equal value given in these tables. For example: It is desired to change 4 meters to feet, or to find how many feet there are in 4 meters. From the table, 1 meter = 3.28 feet. Then 4 meters = 4 × 3.28 = 13.12 feet.

Length

1 **mil** = .0254 millimeters = .001 inches

1 **millimeter** = 39.37 mils = .03937 inches

1 **centimeter** = .3937 inches = .0328 feet

1 **inch** = 25.4 millimeters = .083 feet = .0278 yards = 2.54 centimeters

1 **foot** = 304.8 millimeters = 12 inches = .333 yards = .305 meters

1 **yard** = 91.44 centimeters = 36 inches = 3 feet = .914 meters

1 **meter** = 39.37 inches = 3.28 feet = 1.094 yards

1 **kilometer** = 3281 feet = 1094 yards = .6213 miles

1 **mile** = 5280 feet = 1760 yards = 1609 meters = 1.609 kilometers

Area

1 **circular mil** = .7854 square mils = .0005067 square millimeters = .0000007854 square inches

1 **square mil** = 1.273 circular mils = .000645 square millimeters = .000001 square inches

1 **square millimeter** = 1973 circular mils = 1550 square mils = .00155 square inches

1 **square centimeter** = 197300 circular mils = .155 square inches = .00108 square feet

1 **square inch** = 1273240 circular mils = 6.451 square centimeters = .0069 square feet

1 **square foot** = 929.03 square centimeters = 144 square inches = 0.1111 square yards = .0929 square meters

1 **square yard** = 1296 square inches = 9 square feet = .000207 acres

1 **square meter** = 1550 square inches = 10.7 square feet = 1.195 square yards = .000247 acres

1 **acre** = 43560 square feet = 4840 square yards = 4047 square meters = .004047 square kilometers = .001562 square miles

1 **square kilometer** = 10,760,000 square feet = 1,196,000 square yards = 247 acres = .3861 square miles

1 **square mile** = 27,880,000 square feet = 3,098,000 square yards = 2,590,000 square meters = 640 acres = 2.59 square kilometers

Volume

1 circular mil-foot = .000,009,424 cubic inches.

1 cubic centimeter = .061 cubic inches = .0021 pint (liquid) = .0018 pint (dry)

1 cubic inch = 16.39 cubic centimeters = .0346 pint (liquid) = .0298 pint (dry) = .0043 gallons = .0005787 cubic feet

1 pint (liquid) = 473.17 cubic centimeters = 28.87 cubic inches

1 pint (dry) = 550.6 cubic centimeters = 33.60 cubic inches

1 quart (liquid) = 946.36 cubic centimeters = 57.75 cubic inches = 2 pints (liquid) = .25 gallons

1 liter = 1000 cubic centimeters = 61.023 cubic inches = 2.1133 pints (liquid) = 1.8162 pints (dry) = .098 quarts (dry) = .2642 gallon (liquid) = 0.03531 cubic feet

1 quart (dry) = 1101 cubic centimeters = 67.20 cubic inches = .03889 cubic feet

1 gallon = 3785 cubic centimeters = 231 cubic inches = 8 pints = 4 quarts = .1337 cubic feet = .004951 cubic yards

1 cubic foot = 28317 cubic centimeters = 1728 cubic inches = 28.32 liters = 7.48 gallons = .02832 cubic meters

1 cubic yard = 46656 cubic inches = 27 cubic feet = .7646 cubic meters

1 cubic meter = 61023 cubic inches = 1000 liters = 35.31 cubic feet = 1.308 cubic yards

Weight

1 milligram = .01543 grains = .001 grams

1 grain = 64.80 milligrams = .002286 ounces* (avoirdupois)

1 gram = 15.43 grains = .03527 ounces = .002205 pound*

1 ounce = 437.5 grains = 28.35 grams = .0625 pound = 16 drams

1 pound = 7000 grains = 453.6 grams = 256 drams = 16 ounces = 0.4536 kilograms

1 ton = 2000 pounds = 907.2 kilograms = 0.9072 metric tons = .8928 long tons

1 metric ton = 2205 pounds = 1000 kilograms = 1.102 short tons = .9842 long tons

1 long ton = 2240 pounds = 1.12 short tons = 1.016 metric tons

*The pound and ounces are avoirdupois weight.

Energy and Torque

1 watt-second = 1 joule = .7376 foot-pound
= .0009480 British thermal units = .0002778 watt hours

1 foot-pound = 1.356 watt-seconds = .001285 British thermal units
= .0003766 watt-hours = .000000505 horsepower-hours

1 British thermal unit = 1055 watt-seconds = 778.1 foot-pounds
= .293 watt-hours = .000393 horsepower-hours

1 watt-hour = 3600 watt-seconds = 2655.4 foot-pounds
= 3.413 British thermal units = .001341 horsepower-hours

1 horsepower-hour = 2,685,600 watt-seconds = 1,980,000 foot-pounds
= 273,700 kilogram-centimeters = 746 watt-hours

Power

1 foot-pound per minute = .02260 watts = .0000303 horsepower

1 watt = 44.26 foot-pounds per minute = .001 kilowatts

1 horsepower = 33,000 foot-pounds per minute = 746 watts
= 550 foot-pounds per second

1 kilowatt = 44256.7 foot-pounds per minute = 1.341 horsepower

Circles

Circumference of a circle = diameter $\times$ 3.1416

Circumference of a circle = radius $\times$ 6.2832

Area of a circle = diameter squared $\times$ .7854

Area of a circle = circumference squared $\times$ .07958

Area of a circle = half the circumference $\times$ half its diameter

Radius of a circle = circumference $\times$ .159

Diameter of a circle = circumference $\times$ .3183

Diameter of a circle = square root of the area $\times$ 1.128

Sphere

Volume of a sphere = surface of a sphere $\times \frac{1}{6}$ its diameter

Volume of a sphere = the cube of the diameter $\times$ .5236

Volume of a sphere = the cube of the radius $\times$ 4.188

Volume of a sphere = the cube of the circumference of the sphere $\times$ .0168

Area of the surface of a sphere = the circumference $\times$ its diameter

Area of the surface of a sphere = diameter squared $\times$ 3.1416

COPPER WIRE TABLE

Gauge No.*	Diameter in Mils	Cross Section Area		Ohms per 1000 Feet 25°C (=77°F)	Pounds per 1000 Feet
		Circular Mils	Square Inches		
0000	460.	212000.	0.166	0.0500	641.
000	410	168000.	.132	.0630	508.
00	365.	133000.	.105	.0795	403.
0	325.	106000.	.0829	.100	319.
1	289.	83700.	.0657	.126	253.
2	258.	66400.	.0521	.159	201.
3	229.	52600.	.0413	.201	159.
4	204.	41700.	.0328	.253	126.
5	182.	33100.	.0260	.319	100.
6	162.	26300.	.0206	.403	79.5
7	144.	20800.	.0164	.508	63.0
8	128.	16500.	.0130	.641	50.0
9	114.	13100.	.0103	.808	39.6
10	102.	10400.	.00815	1.02	31.4
11	91.	8230	.00647	1.28	24.9
12	81.	6530.	.00513	1.62	19.8
13	72.	5180.	.00407	2.04	15.7
14	64.	4110.	.00323	2.58	12.4
15	57.	3260.	.00256	3.25	9.86
16	51.	2580.	.00203	4.09	7.82
17	45.	2050.	.00161	5.16	6.20
18	40.	1620.	.00128	6.51	4.92
19	36.	1290.	.00101	8.21	3.90
20	32.	1020	.000802	10.04	3.09
21	28.5	810.	.000636	13.1	2.45
22	25.3	642.	.000505	16.5	1.94
23	22.6	509.	.000400	20.8	1.54
24	20.1	404.	.000317	26.2	1.22
25	17.9	320.	.000252	33.0	0.970
26	15.9	254.	.000200	41.6	.769
27	14.2	202.	.000158	52.5	.610
28	12.6	160.	.000126	66.2	.484
29	11.3	127.	.0000995	83.4	.384
30	10.0	101.	.0000789	105.	.304
31	8.9	79.7	.0000626	133.	.241
32	8.0	63.2	.0000496	167.	.191
33	7.1	50.1	.0000394	211.	.152
34	6.3	39.8	.0000312	266.	.120
35	5.6	31.5	.0000248	335.	.0954
36	5.0	25.0	.0000196	423.	.0757
37	4.5	19.8	.0000156	533.	.0600
38	4.0	15.7	.0000123	673.	.0476
39	3.5	12.5	.0000098	848.	.0377
40	3.1	9.9	.0000078	1070.	.0299

*The gauge number refers to American Wire Gauge, often called Brown & Sharpe Gauge, that is used for copper wire. A mil is $\frac{1}{1000}$ of an inch.

Comparison of Centigrade and Fahrenheit Thermometers

Water boils at......... { 100 degrees Centigrade (C. or Cent.)
212 degrees Fahrenheit (F. or Fahr.) }

Water freezes at....... { 0 degrees Centigrade (C. or Cent.)
32 degrees Fahrenheit (F. or Fahr.) }

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32.0				
1	33.8	36	96.8	71	159.8
2	35.6	37	98.6	72	161.6
3	37.4	38	100.4	73	163.4
4	39.2	39	102.2	74	165.2
5	41.0	40	104.0	75	167.0
6	42.8	41	105.8	76	168.8
7	44.6	42	107.6	77	170.6
8	46.4	43	109.4	78	172.4
9	48.2	44	111.2	79	174.2
10	50.0	45	113.0	80	176.0
11	51.8	46	114.8	81	177.8
12	53.6	47	116.6	82	179.6
13	55.4	48	118.4	83	181.4
14	57.2	49	120.2	84	183.2
15	59.0	50	122.0	85	185.0
16	60.8	51	123.8	86	186.8
17	62.6	52	125.6	87	188.6
18	64.4	53	127.4	88	190.4
19	66.2	54	129.2	89	192.2
20	68.0	55	131.0	90	194.0
21	69.8	56	132.8	91	195.8
22	71.6	57	134.6	92	197.6
23	73.4	58	136.4	93	199.4
24	75.2	59	138.2	94	201.2
25	77.0	60	140.0	95	203.0
26	78.8	61	141.8	96	204.8
27	80.6	62	143.6	97	206.6
28	82.4	63	145.4	98	208.4
29	84.2	64	147.2	99	210.2
30	86.0	65	149.0	100	212.0
31	87.8	66	150.8		
32	89.6	67	152.6		
33	91.4	68	154.4		
34	93.2	69	156.2		
35	95.0	70	158.0		

Decimal Equivalents

		1/64	.015625
	1/32		.03125
		3/64	.046875
1/16			.0625
		5/64	.078125
	3/32		.09375
		7/64	.109375
1/8			.125
		9/64	.140625
	5/32		.15625
		11/64	.171875
3/16			.1875
		13/64	.203125
	7/32		.21875
		15/64	.234375
1/4			.25
		17/64	.265625
	9/32		.28125
		19/64	.296875
5/16			.3125
		21/64	.328125
	11/32		.34375
		23/64	.359375
3/8			.375
		25/64	.390625
	13/32		.40625
		27/64	.421875
7/16			.4375
		29/64	.453125
	15/32		.46875
		31/64	.484375
1/2			.5
		33/64	.515625
	17/32		.53125
		35/64	.546875
9/16			.5625
		37/64	.578125
	19/32		.59375
		39/64	.609375
5/8			.625
		41/64	.640625
	21/32		.65625
		43/64	.671875
11/16			.6875
		45/64	.703125
	23/32		.71875
		47/64	.734375
3/4			.75
		49/64	.765625
	25/32		.78125
		51/64	.796875
13/16			.8125
		53/64	.828125
	27/32		.84375
		55/64	.859375
7/8			.875
		57/64	.890625
	29/32		.90625
		59/64	.921875
15/16			.9375
		61/64	.953125
	31/32		.96875
		63/64	.984375
1			1.

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